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MANGROVE FEASIBILITY STUDY
GAMBIA FORESTRY PROJECT NO. 635-0205

FINAL REPORT

CHECCHI AND COMPANY

September 11, 1981

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September 11, 1981

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September 11, 1981

Mr. Ousman Othman
Permanent Secretary
Ministry of Water Resources and Environment
Government of The Gambia
Banjul, The Gambia

Dear Mr. Secretary:

Enclosed are 50 copies of the final report of the Mangrove Feasibility Study, Gambia Forestry Project 635-0205, as required by our contract with the Ministry of Water Resources and Environment dated 12 March 1981.

As you know, a draft final report was reviewed by representatives of the Government of The Gambia and USAID at a meeting held 21 August 1981 in Banjul and approved subject to certain specific suggestions. All of the suggestions made during our recent visit have been incorporated into this final text; photographs have been added and a complete appendix attached.

On behalf of the members of our study team and Checchi and Company, I express to you, Mr. Secretary, our sincere appreciation for the opportunity of working with you and for the cooperation and assistance given to us by a large number of people.

The urgency for action to deal with Rhizophora dieback is clearly understood by those who have reviewed the report. Our report lays out, in broad outline, an action program for doing so.

We are ready and willing to assist you in any further ways we can.

Sincerely yours,

Fred H. Hubbard

Fred H. Hubbard
Study Coordinator

cc: AID/Banjul (50 copies)

SUMMARY

This study has investigated the technical, economic, social, and environmental feasibility of alternatives for harvesting, processing, and marketing mangroves in The Gamiba.

During the months of May and June 1981, a team of nine specialists from Checchi and Company, Washington, D.C., USA, under contract with the Ministry of Water Resouces and Environment, Banjul, The Gambia, conducted field studies, interviewed a large number of people, and reviewed literature on the subject. The sources of information are incorporated into the text and cited in the appendices.

Prior to coming to The Gambia, we worked on the assumption contained in our terms of reference that the mangroves we were to study would be affected adversely by the proposed barrage and that our attention should focus initially on mangroves above the barrage and secondarily on a management program for mangroves below the barrage.

Field visits indicated that since the time previous studies were made, serious mortality has occurred in Rhizophora mangroves. In some areas, such as at Bintang Bolon, nearly 100 percent of the trees are dead and unsalvageable.

Since 1978, losses in the Rhizophora stands have been enormous. Prospects are that most of the Rhizophora mangrove will be gone in a few years. The immediate cause of the high mortality appears to have been disease, but it is not clear whether or not disease has been the primary cause of the losses or if some environmental factor had weakened the trees to the point where they are particularly vulnerable to disease.

One big effect of the changed resource situation has been to rule out most of the industrial development opportunities that had previously been thought worth considering because there is no assurance that the Rhizophora mangrove will last long enough to amortize large investments in manufacturing plants, and because of the deteriorating timber supply situation in the whole of The Gambia. It was determined that the best use of the remaining mangrove would be for fuelwood.

It will be necessary to conduct an accelerated harvesting program if most of the Rhizophora mangrove is to be salvaged before it dies.

A preliminary analysis indicated that the mangrove can be harvested and delivered to the greater Banjul area at a cost below that currently being paid for fuelwood.

There are two main advantages in emphasizing fuelwood production: labor-intensive harvesting procedures with low capital investments; introduction of large quantities of mangrove into the fuelwood market will, in the short run, reduce cutting of upland forest, providing time to do something about timber shortages in The Gambia.

There appears to be no serious difficulty in mobilizing manpower necessary for accelerated harvesting.

The dying out of Rhizophora racemosa places the Gambia River in jeopardy. This river-front species plays a vital role in maintaining shoreline stability and protecting the marine environment. For this reason, even if dying mangroves are not salvaged, shorelines must be replanted.

GENERAL CONCLUSIONS

- A major portion of the Rhizophora mangrove protecting the shoreline of the Gambia River will be dead within five years.
- The immediate cause of mortality appears to be disease but other environmental factors may also be involved.
- Dead, dying, and harvested mangroves need to be replaced by plantings especially to protect streambanks and the adjacent environment.
- The task of salvaging dead and dying mangroves could make a significant contribution to the Gambian economy.
- Fuelwood is the most feasible overall use of mangrove.
- Mangrove management on a sustained yield basis could provide long-term benefits to The Gambia.
- Existing organizations and institutions need to be improved, strengthened and/or developed to implement a mangrove harvesting, processing, and marketing program.

GENERAL RECOMMENDATIONS

- The Gambia should undertake a mangrove harvesting program with principal emphasis on fuelwood production.
- A quasi-public organization should be established to carry out and coordinate the program of harvesting and marketing the fuelwood.
- The Department of Forestry should be made fully responsible for designating cutting areas and supervising cutting and environmental practices in connection with the mangrove harvesting.
- A pilot-scale logging operation should be conducted before full-scale harvesting begins.
- The Department of Forestry should be directed to initiate a tree planting program as soon as possible to replace dead, dying, and harvested trees.
- Causes and extent of the Rhizophora dieback disease should be investigated intensively and extensively.
- Information required to implement a mangrove management and harvesting program should be obtained from other countries.

ACKNOWLEDGEMENTS

Many people assisted us in this study; their names are listed in Appendix Eight of this report with the place of initial contact. We regret that we may not have included everyone; in many cases, it was impossible to record names because so many people participated, entering and leaving the discussions.

Obtaining information through interviews was often unnecessary when observations could suffice: watching mangrove woodcutters, for example, or measuring the fuelwood stacked at roadsides or working up through bolons and into swamps to examine dead trees.

The most important source of information for our study was Gambians directly or indirectly involved or interested in some aspect of mangrove harvesting, processing, and marketing. Retailers, woodcutters, wood and metal workers, truck drivers, farmers, fishermen, equipment dealers, local officials, and housewives all provided valuable insights. Officials in the Banjul area and upriver were especially cooperative, frequently working with us after hours and on weekends. These included officials from many international agencies, national, provincial and local governments, and volunteer groups.

We wish to acknowledge in particular the cooperation received from the Ministry of Water Resources and Environment: Forestry, Water Resources, and Fisheries Departments. The Forestry Department provided us with field staff assistance, a boat and motor, and a chain saw. Water Resources analyzed water quality samples and Fisheries lent the services of a field biologist. All three agencies provided considerable statisitcal data.

The Gambia/German Forestry Project cooperated with our study both on site visits and in use of aerial photographs.

USAID assisted by introducing us to many officials, in easing our way into the study, in permitting use of aerial photographs, in exchanging ideas on the respective alternatives, and in providing general support.

The British High Commission, Banjul, lent us the use of a number of barrage study reports. Officials in the Ministry of Overseas Development in London and Surbiton, England, were extremely cooperative in providing data and maps and in allowing us an opportunity to discuss our findings with them.

We found the semi-formal meetings arranged for us by the Ministry of Water Resources and Environment most useful in directing our work and in helping us fit our technical knowledge into a Gambian context.

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PART ONE - INTRODUCTION

This report contains findings of The Gambia mangrove feasibility study team. It essentially follows an outline presented in our Inception Report dated April 30, 1981 and approved by the Government of The Gambia. Both our proposal, dated August 28, 1980, and our Inception Report were based on the scope of work outlined in an earlier project paper (1). However, when initial field studies were started shortly after the team arrived in The Gambia in May 1981, a refinement of our terms of reference was necessary to take into account evidence of the actual and impending demise of substantial numbers of mangrove trees.

Development of alternative methods for technical, economic, social, and environmentally feasible harvesting, processing, and marketing mangroves above a proposed saltwater barrier was the priority focus of our study. In addition to development of alternative means for exploiting mangroves above the barrier, the team also examined programs for rehabilitation and management of areas below the barrage. Although these approaches are consistent with our terms of reference, they were of necessity modified as a result of the present condition of mangroves throughout The Gambia.

Our report thus accounts for both the explicit requirements as stated in the Inception Report and the importance of dealing with the recently documented condition of mangroves. We believe this approach provides an unusual opportunity to respond to one of the most critical needs of The Gambia, that of satisfying on a short and long-term basis the energy requirements of the country. Discussions with individuals in The Gambia led us to believe that this positive approach was widely accepted.

Context of Study

Descriptions of the socio-economic and environmental conditions of The Gambia are given in a number of sources (2, 3, 4, 5, 6, 7) and need not be repeated here except to emphasize that the needs of The Gambia are great and its resources are limited; a growing population has strained the resources the country does have and this awareness gives rise to concerns about development programs. One important resource of The Gambia is its river, a body of water stretching from its source in the Fouta Djalon mountains in Guinea and winding its way through Senegal and The Gambia for 1,100 kilometers. Unfortunately for agricultural production purposes, the reduced flow of fresh water during the dry season permits intrusion of salt water as far as 220 kilometers upstream from the river's mouth (3).

The Gambia is a small country--10,360 km^2--dependent for its economic well-being on the rains that nourish its basic life support system of rainfed agriculture. Lately, these rains have been insufficient

to satisfy even fundamental requirements, and food imports are required, worsening export-import balances. Recent droughts have added support for managing river water in The Gambia for agricultural production purposes. Hence, to augment the present single crop, agriculture, a barrage has been proposed to prevent salt water from moving upriver and to hold fresh water from the rainy season for two-crop irrigation. It was the anticipated effect of this barrage on some 8,700 hectares of mangroves above the barrier and what to do about the situation that gave rise to this mangrove study.

Our terms of reference do not require analysis of the barrage nor of its impact except as it concerns mangroves and the natural and human systems that may be changed by harvesting, processing, and marketing this wood resource. Reports prepared on the impact of the barrage (8, 9) indicate many possible changes, such as transition of the area above the barrage from a tidal brackish water regime to a freshwater ecosystem. Not only are mangroves apt to be influenced by these changes, but a different flora is likely to enter areas previously dominated by mangroves. Changes in aquatic animal life can be expected too.

The potential loss of mangroves, either as a result of the barrage or from natural causes, brings into focus the critical matter of energy, chiefly as it relates to fuel for cooking. Most of the Gambian population is dependent on fuelwood for cooking and most of that wood now comes from upland sources. Estimates made by Openshaw (12) indicate that at the present rate of consumption, these upland supplies may be exhausted by the year 2000. Hence, anything that may provide an alternative to upland supplies and/or can be substituted to buy time to replenish these supplies requires serious consideration. Mangroves could satisfy some of the fuelwood demand. Moreover, given the deteriorating condition of the mangrove resource, exploitation and subsequent management would be a positive and rational response to the unforeseen heavy lossess now occurring.

Gambia Forestry Project

Concern about mangroves is part of a larger concern about forests in The Gambia. This, in turn, involves energy, agriculture--both in competition for land and wood as a crop--and overall basin development programs. To take one of these concerns, that of forests in The Gambia, indicators point to continued depletion, because of increasing demand for forest products due to population growth, continuing clearing of forests for agriculture, uncontrolled fires started for land-clearing purposes, soil desiccation, wind and water erosion, and drought (1). Most Gambians rely on the forest for fuel and building materials with as much as 99 percent of wood being used for fuelwood. These indicators have suggested to responsible authorities that programs are needed to prevent the predictions of forest depletion by the year 2000 from coming true.

Forestry programs in The Gambia are relatively new, beginning in 1951 with the establishment of a Forestry Division in the Department of Agriculture within the Ministry of Agriculture and Natural Resources. A forestry law written in 1977 requires licensing of all commercial forest exploitation and gives the department full authority to control such activities in the country. Rules for control of brush fires and protection of endangered species are included in the law. However, inadequate data, equipment, and financial resources for enforcement of the law have prevented the country from making all the forestry progress it might. Various donors have been attracted to help improve the forestry situation in The Gambia. Among them is USAID, which has provided funding for the Gambia forestry project (No. 635-0205), of which this mangrove feasibility study is one of five parts. Other projects include training, outreach (a media campaign), production of wood in plantations and woodlots, and utilization (purchase and installation of logging and milling equipment). The project is related to Gambian Government and CILSS priorities and to the most recent AID Country Development Strategy Statement (1).

Approach and Procedures

Conceptual Framework. In reviewing the mangrove situation, forestry conditions and resource limitations in The Gambia, and the specific requirements set forth in our scope of work, we attempted to develop an approach that would be compatible with the overall objectives of development in The Gambia and the Gambia River Basin. Thus, we tried to prepare a framework that integrated the respective requirements so they would complement each other in a factually-based management program that accounted for technical, economic, social, environmental, and institutional considerations. For example, sections labeled "Economics" or "Ecology" or "Sociology" that are unrelated to the overall objective of the study are not found in the report. On the contrary, we saw harvesting and marketing as a continuing process starting with acquisition of basic factual information on the resource. It is a process that requires consideration of institutional and infrastructural requirements for implementing a work program that meshes with other development activities. We were aided in conceptualizing a comprehensive process by an analysis of the specific requirements contained in the scope of work for each team member.

We were further aided in preparing our approach by the views of officials in the Ministry of Water Resources and Environment (WREN) to the effect that alternatives should be prepared and analyzed for Gambian Government decision--not simply statements of recommendations from outside consultants. Whatever alternatives were infeasible should be explained with a full description of the reason for rejection. In our assessment of the mangrove situation and of the study requirements, seven major areas appeared which synthesized specific requirements and gave words to the framework for the comprehensive approach we pursued.

The seven study areas which serve as topic chapters in Part Two of this report were initially prepared under the leadership of one or more individuals who also contributed to the chapter.

Methodology. Three main methods were employed by team members: literature collection and review; interviews with individuals with particular knowledge of some aspect of the study, such as woodcutters, wood retailers or processors, government officials or village chiefs; and visits to the mangrove swamps for sampling, photo verification, data collection, and inspection of stand quality. Of special importance was the study prepared by the Land Resources Development Centre from data collected by Johnson and Abell (10, 11) and the interpretation of aerial photos provided by the Gambian/German inventory project (GRTZ) and USAID. Areas visited are cited throughout the text and names of persons who assisted in the study are listed in an appendix. Literature sources are listed at the end of each chapter.

During the team's visit to The Gambia, two semi-formal sessions were held at WREN. The first, on June 3, was for the purpose of presenting a progress report. Four key topics were discussed: dead and dying mangroves; resources available for harvesting mangroves; alternative uses of mangroves; and institutional arrangements for mangrove harvesting. The purpose of that meeting was to solicit preliminary views of these topics from GOTG and USAID in an effort to explore as many options as possible. At a second meeting on June 18, some of the key topics on which the final report might focus were tested for GOTG and USAID reaction. These included use of mangroves; harvesting procedures appropriate to the most desirable use; rehabilitation and management procedures following harvesting; measures to assure that soils will support management programs; and organizational and institutional resources to implement a management program. These semi-formal meetings were extremely useful to team members in obtaining experience and insights of officials, but, as valuable as they were, intensive one-to-one interviews with persons on the spot who had direct experience with cutting, hauling, selling, barging, or farming in mangrove soils, for example, provided the most detailed and intimate knowledge.

A third meeting was held in Banjul on August 21, 1981 to review the final draft report. A number of suggestions to improve the report were made and these suggestions were subsequently incorporated into this report.

Organization of Report

There are four parts to this report: Part One, Introduction; Part Two, Study Areas Covered; Part Three, Findings and Conclusions; and Part Four, Recommendations. Part Two is the longest and most detailed because data obtained by each team member are presented, analyzed, and assessed. Part Two is supplemented by extensive tabular and detailed

materials in appendices. Part Three summarizes findings and conclusions that lead to the recommendations. It notes the alternatives that seemed worthy of consideration, selecting those that seemed most appropriate, and explaining why the others were rejected. Part Four presents recommendations for dealing with the unique problems of harvesting, processing, and marketing mangroves.

Whenever possible, detailed descriptions, charts, and tabular materials have been included in the appendix to shorten the text and enhance readability.

NOTES REGARDING SOURCE MATERIAL

1. U.S. Agency for International Development, Gambia Forestry Project, Project Paper, Proposal and Recommendations to the Project Review Committee, approved August 3, 1979.

2. John Dunsmore, et al, The Agricultural Development of The Gambia: An Agricultural Environmental and Socio-economic Analysis, LRD 22, L976.

3. UNDP, Development of The Gambia River Basin, Final Mission Report, April 1980.

4. Barbara Mittleholtz, National Water Resources Law Inventory, The Gambia, West Africa, August 1977.

5. Fred H. Hubbard, Report on Establishment of a Permanent Environmental Unit in The Government of the Gambia, UNDP, 1978.

6. Barbara and Kenneth Mittleholtz, The Gambia--An Overview of its Human Environment, Attorney General's Chambers, Banjul, The Gambia, Dec. 1976.

7. UNDP, Country Programme for Gambia, DP/GC/GAM/R.2, September 1977.

8. Gambia River Basin Development Organization, The Gambia Estuary Barrage Study--Stage II, prepared by Coode & Partners and Peat, Marwick, Mitchell & Co. in association with Ministry of Agriculture, April 1979, five volumes.

9. Fred H. Hubbard, Report on a Development Programme for the Gambia River Basin, Environment, Environmental Health, Tourism, UNDP, October 1977.

10. M. S. Johnson, Inventory of Mangrove Above the Proposed Gambia River Barrage at Yelitenda, The Gambia, Project Report 54, Land Resources Development Centre, Surbiton, Surrey, England, 1978.

11. T. M. Abell, Letter to R. J. McEwan, May 28, 1980, Overseas Development Administration, Land Resources Development Centre, Surbiton, Surrey, England.

12. Openshaw, Keith, Forest Economic Consultant, The Gambia: A Wood Consumption Survey and Timber Trend Study 1970-1980 - Report to Gambia Land Resources Development Project.

1. Gambia downriver once looked like this scene from Abuko Nature Reserve

2. Gambia upriver is largely cleared for agriculture with a few large trees still standing.

3. Land is cleared by cutting and burning. After cultivation, land is allowed to lie fallow for a period.

PART TWO - STUDY AREAS

Part Two of the mangrove feasibility study report contains seven chapters that provide substantive background to the conclusions and recommendations that follow in Parts Three and Four. Chapters have been arranged in an order that flows from description of the physical resource through operational procedures to integration of a mangrove harvesting, processing, and marketing program into other sectors of the economy. The chapter titles are:

1. The Mangrove Resource
2. Utilization of the Mangrove Resource
3. Harvesting Systems
4. Institutional Infrastructure and Manpower Mobilization
5. Environmental Aspects of Mangrove Utilization
6. Financial Prospects
7. Integration of a Mangrove Program into the Economy

Each chapter builds on the previous one in an effort to describe and analyze a very complicated situation as comprehensively as possible.

CHAPTER ONE
THE MANGROVE RESOURCE

This chapter discusses the past and projected trend of mangrove volume and quality and factors behind changes that have occurred and are occurring. The chapter also considers what is known about the dieback disease of Rhizophora mangroves in The Gambia, how it compares with a similar disease in Florida, USA, some possible explanations for the recent appearance of the disease in epidemic proportions in The Gambia, and the future outlook for the Gambia's Rhizophora forest resource.

Basis for the Mangrove Inventory Estimates in this Report

In 1978, M.S. Johnson conducted an inventory, based in 1972 aerial photographs, of mangrove forest above the site of the proposed barrage at Yelitenda (1). The field sampling technique used took account of changes between then and 1978. In 1980, T.M. Abell made preliminary estimates of the timber volume below the barrage site using 1972 aerial photographs (2). Since Abell was not in a position to take field samples, he used Johnson's plot data from above the barrage to update his own estimates to 1978.

Johnson's and Abell's data have been adapted to meet the special requirements of this study. On the basis of our own field inspection, the timber inventory estimates have been brought forward to 1981 and projected to 1986. The principal factor of change has been the rapid rate of stand deterioriation. Johnson noticed this was happening in 1978 but losses were apparently just beginning to be noteworthy at that time.

Our own estimates of timber volumes in 1981 and 1986 are based on field observations without the advantage of actual measurements. For that reason, details in the tables may have a wide margin of error. Nevertheless, the main conclusions drawn from the numbers in the aggregate present what we believe is as accurate a picture of the outlook as can be anticipated at present. A more accurate estimate than currently exists is fortunately now in progress. The Gambian/German inventory team, supported by GTZ, was in the field during our study and is at work inventorying the total wood resource of The Gambia. We understand that they have been requested to give particular attention to the mangrove situation.

The Mangrove Stand Yesterday, Today, and Tomorrow

For 170 kilometers upstream, there are well-developed mangroves in the process of dynamic change. After what appears to have been a

long period of relative stability, the forest is deteriorating at a rapid rate. In only a few years, one-fifth of the timber has died (Table 1.1). We expect that by 1986 only 60 percent of the previously reported mangrove timber volume may remain. However, this is only part of the story.

- By 1986, 52 percent of the largewood estimated to be in the mangrove forest in 1978 may be gone and at least 75 percent of the large Rhizophora timber--the best part of the forest--will probably have died (Table 1.1).

- In Johnson's and Abell's 1978 estimates, 61 percent of the total volume was Rhizophora species. By 1986, the proportion will probably have fallen to 36 percent and Avicennia species will dominate what is left of the forest (Table 1.1).

- Previously, 58 percent of the timber volume was in largewood. By 1986, the proportion will probably fall to 46 percent (Tables 1.1 and 1.2).

- The mortality of mangrove timber has been especially severe in some areas. In a few spots, in Bintang Bolon for example, nearly 100 percent losses have occurred.

- These changes have occurred in the absence of a significant amount of timber cutting.

The substantial loss of large Rhizophora since 1978 was evident both from field observation and 1980 aerial photographs. It appears that about 40 percent of these large trees had died between 1978 and 1980. Because of the great numbers of dead tops and cankers on living trees, we anticipate a further reduction of about 35 percent by 1986. Thus, the volume of large Rhizophora trees may be reduced by 75 percent between 1978 and 1986 because of the dieback.

Since proportionately more of small Rhizophora trees died before 1978 (1), a slower rate of decline was assumed in smallwood volume between 1978 and 1986. The following tables summarize the situation.

Table 1.1

TREND OF MANGROVE TIMBER VOLUME BY SIZE OF WOOD AND GENUS

Genus	1978 3/	1981	1986
	(thousand cubic meters)		
Largewood 1/			
Rhizophora	1,582	950	400
Avicennia	700	700	700
Total	2,282	1,650	1,100
Smallwood 2/			
Rhizophora	829	640	445
Avicennia	829	829	829
Total	1,658	1,469	1,274
Grand Total	3,940	3,119	2,374

1/ Includes stemwood only of trees larger than 20 cm in diameter.

2/ Includes tops of all trees and stemwood of trees 20 cm in diameter and smaller.

3/ Based on Johnson's and Abells data (1) (2).

Table 1.2

TREND OF MANGROVE TIMBER VOLUME BY SIZE OF WOOD AND LOCATION

	1978	1981	1986
	(thousand cubic meters)		
Above Barrage Site			
Smallwood 1/	225	200	132
Largewood 2/	704	581	346
Total	929	781	478
Below Barrage Site			
Smallwood	1,433	1,269	1,142
Largewood	1,578	1,069	754
Total	3,011	2,338	1,896
Above and Below			
Smallwood	1,658	1,469	1,274
Largewood	2,282	1,650	1,100
Total	3,940	3,119	2,374

1/ Includes tops of all trees and stemwood of trees 20 cm in diameter and smaller.

2/ Includes stemwood only of trees larger than 20 cm in diameter.

The Utility of the Dead Timber

In dryland situations, timber that has died is ordinarily sound enough to be used for fuel for from a few to many years after. This is not so in the mangrove swamps where dead trees quickly become riddled with insect holes and decay, fall over, and are completely unusable in a very short time. Dying trees or trees that have just died do have usable wood. Some of the smaller dead and dying trees can be salvaged. However, it is far too dangerous to cut very large dead and dying trees with big dead limbs that may break off without the slightest warning. These must be written off completely.

What is Known About the Dieback Disease

In 1978, Johnson (1) reported that there had been considerable mortality and dieback in the Gambian mangroves. This was evident because the 1972 aerial photographs he used for his mangrove inventory

showed no detectable damage in some areas that had no live trees in 1978. He concluded that death and dieback of trees occurred in the 1972 to 1978 period and suggested that it was probably associated with abnormal drought conditions of those years.

Johnson reported very little dieback in Rhizophora mangrove forest with canopy cover over 20 meters high; he noted that there had been much dieback or complete death in the Rhizophora forest 7 to 20 meters high; and that there was much dieback in the crowns of Rhizophora forest of less than 7 meters tall.

Our field study in 1981 revealed large areas of dead and dying Rhizophora trees, especially in the greater than 20 meter class. The extent of the heavy kill is shown dramatically in the 1980 1:25,000 false color infrared photographs where canopies of live trees appeared bright red and trunks of dead trees were gray. These photographs showed, for example, a large area near Darusalam, on Bintang Bolon, where there was an estimated 95 percent kill of tall (above 20 meters) and medium size (7 to 20 meters) Rhizophora trees, as well as a substantial kill of low forest (less than 7 meters). On-site inspection at Darusalam, where three Rhizophora species occur, showed that all three were affected by dieback.

The Rhizophora trees affected by dieback have galls and cankers on branches, trunks, and prop roots. These galls and cankers have a gnarled appearance. In many cases, dead branches with brown leaves were seen on infected trees; in rare instances, entire trees had dead leaves. Some large trees that died at least two years before our visit showed extensive galls on prop roots which indicated the dieback had affected them for a long time before they died. Galls were not found on first-year Rhizophora seedlings.

Comparison of Gambian Dieback with the Florida Disease

Dieback disease symptoms in The Gambia are similar to those encountered in Florida, where there is an endemic gall disease of Rhizophora mangle, described in 1975 by Olexa and Freeman (3). They tentatively identified the causative agent as a fungus, Cylindrocarpon didymum (Hartig) Wallenw. The same authors reported in 1978 that they had consistently cultured Cylindrocarpon didymum from Rhizophora gall tissue and that they had demonstrated the pathogenicity of the organism with field inoculations of Rhizophora trees (4). They found the disease to be slow to develop; initial symptoms from inoculation of Rhizophora mangle trees with laboratory cultured Cylindrocarpon didymum required six months to appear. Wounded and inoculated trees developed roughened calluses and galls from which the fungus could be readily isolated. The gall disease of Rhizophora in Florida apparently kills some trees but is not a major cause of mortality even though in some areas 100 percent of trees have galls.

The disease in The Gambia is widespread and serious. The low incidence of dieback in the greater than 20 meters high Rhizophora forest reported by Johnson (1) compared with the higher incidence in 1981 may simply reflect the slowness of disease development, i.e., many of the tall trees, like those of intermediate and smaller size, were infected in 1978 but it takes longer to kill large trees than small trees.

Possible Reasons for the Recent Epidemic in The Gambia

Possible explanations for the recent epidemic are:

1. That a more virulent strain or species of pathogen is involved in The Gambia than in Florida and elsewhere; or

2. That some environmental change has come about in recent years that makes the mangrove weaker or the pathogen more effective.

The appearance of new strains of plant pathogenic fungi are well documented (5). Also, plant pathologists have long recognized that environmental factors can favor a pathogen or induce a stress that make forest trees more sensitive to dieback (6).

Among the possible factors that might be involved in recent environmental changes which could influence the mangrove-pathogen system are biological changes, drought, and siltation. We have no information on significant change in biological factors in recent years. An example of such a biological factor is an insect vector that might have appeared which can easily transmit the infection.

It is possible that the pathogen might be transmitted or develop more readily under drought or other altered environmental conditions than it does under normal conditions. Although drought might increase the salinity in mangrove soils, this does not seem a likely basis for stress because trees were diseased at Pappa Island, where the maximum dry season salinity is only about 10 parts per thousand; Rhizophora tree roots are regularly exposed to dry season salinities of greater than 45 parts per thousand at Keneba (7). Thus, drought-induced hypersalinity does not seem to be an adequate explanation as a special stress factor for mangroves in recent years.

Another possible explanation may be that when mangroves are not tidally inundated, an increased opportunity is provided for reduced sulfur compounds in the surface layers of fibrous soils to become oxidized to sulfuric acid. Thomas, et al (8) and Johnson (1) have indicated that acid from such soil oxidation could readily kill mangroves. Even if acid formed were not of sufficient concentration to kill trees, it might cause serious stress. Thornton and Giglioli (9) reported both young and old Rhizophora soils in which pH's dropped to 2.5 on drying. Although most Rhizophora soils are ordinarily wet, some

drying and acid formation at the soil surface may occur during neap tide series, even in years of normal rainfall. The extra acidification during the extended dry season of a drought year might be sufficient to stress and weaken trees. A point in favor of this reasoning is that it could explain stress conditions occurring equally at Mandinari and Elephant Island. Mangroves at both locations are growing in potential acid sulfate soil (8).

Another explanation, based on Giglioli and Thornton (10), is that dust buildup is a factor in the slow elevation of mangrove soil levels associated with succession. It is likely that mangrove species which grow in too high a soil elevation might suffer stress. Soil buildup may result from drought-induced increases in Sahara dust. A related possibility is that there could be a greater silt burden deposited on the mangrove soils as a consequence of increased land clearing and erosion upriver in Senegal and Guinea.

None of these possibilities can be evaluated accurately, with present evidence. However, any explanations of stress must account for the fact that there has been no major epidemic in The Gambia for at least the last century. There are many large trees of Gambian *Rhizophora racemosa*, probably more than 100 years old, that do not show evidence of a disease as destructive as the present one.

Outlook for Rhizophora Forests in The Gambia

The present epidemic has evidently developed since 1972. We observed areas of extensive kill in mangroves taller than 20 meters and found that in areas where a tall *Rhizophora* tree has died, nearby trees had galls and often already showed dead branches or tops that were entirely dead. Such evidence suggests that this is a serious epidemic and that a large proportion of the *Rhizophora* trees taller than 20 meters will die within the next five years. If the Gambian mangrove dieback proves to be a virulent new disease, it may pose a threat to *Rhizophora* mangrove forests throughout the world.

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CHAPTER TWO
UTILIZATION OF THE MANGROVE RESOURCE

This chapter discusses the factors that must be taken into account in evaluating the options for utilizing the mangrove resource. It also considers the major options in relation to these factors.

Factors That Must be Considered in Planning for the Utilization of Mangrove

Physical Characteristics of Mangroves. Mangroves along the Gambia River are dense, heavy woods. A solid cubic meter may weigh more than a metric ton. Because of this, mangrove is difficult to saw, chip, slice, and peel. This means that the cost of keeping blades and knives sharp is higher than for most other species. It also means that more energy is required in the process of manufacturing. For example, a particleboard plant using mangrove may be expected to require 50 percent more electrical energy than one using pine (1). Mangrove has been used for lumber and *Rhizophora racemosa* seems reasonably suited for that purpose. However, this species tends to warp and split when sawed into lumber (6). Thus, special care is required in drying sawn wood. *Avicennia africana* is also hard to season and is more difficult to work by hand (see Appendix Two). The density of mangrove does offer one very important advantage. It is an excellent source of energy. A solid cubic meter of green mangrove, chipped, has the equivalent furnace value of 62 imperial gallons of number 6 oil.

The Energy Situation in The Gambia. Like many other developing nations, The Gambia faces a difficult outlook as far as energy is concerned. Its energy problems have been aggravated by the recent world oil crisis but they were going to occur anyway. First, and most important, is the household need for energy. Table 2.1 on the following page, taken from the report Forests and Forestry in the Sahel, indicates that Gambians are currently using more than 900,000 cubic meters of wood each year--99 percent in the form of fuel for cooking and heating (2).

As population climbs from the present 600,000 to one million or so by the year 2000, demand for wood will also rise. A big step to curb the rise in wood consumption was taken in 1980 when production of charcoal was banned because of conversion inefficiencies. Homeowners are now being encouraged to use an inexpensive, home-built clay stove instead of cooking over an open fire. This is expected to reduce domestic fuel consumption by at least 20 percent (5). It may do even better. However, if per capita consumption is reduced no more than 25 percent in the next 20 years, consumption may rise to about 1,200,000 cubic meters in the year 2000.

Table 2.1

ESTIMATED WOOD CONSUMPTION IN THE GAMBIA--1980
(Based on no use of charcoal)

	Per Capita Consumption (cubic meters)	Population	Total Wood Use (cubic meters)
Fuelwood			
Rural	1.66	450,000	747,000
Urban	1.14	150,000	171,000
Total		600,000	918,000
Sawlogs			
Rural	0.01	450,000	4,500
Urban	0.03	150,000	4,500
Total		600,000	9,000
GRAND TOTAL	1.545		927,000

The prospect of wood demands increasing is not a pleasant one. Keith Openshaw noted in 1973 that the woodland had been reduced 30 percent in 15 years (4). Other observers following him have echoed his concern, pointing out that use and abuse of forest land is rapidly exhausting the forest resource of The Gambia (2, 3). One of the more dramatic expressions of the trend is in the 1980 report Development of the Gambia River Basin (3). Table 2.2 presents its assessment of the forest production-consumption situation in the continued absence of an aggressive effort to increase productivity of forest land through more intensive fire protection and management and expanded planting of fast growing trees.

Table 2.2

FOREST PRODUCTION/CONSUMPTION BALANCE IN THE GAMBIA
WITH THE CONTINUATION OF THE PRESENT LEVEL OF FORESTRY PRACTICE

	1976	1985	1990	2000
	Thousands of cubic meters			
Annual Growth	719.6	675.1	632.5	552.3
Annual Consumption	729.8	905.5	1,030.8	1,345.1
Production Deficit	10.2	230.4	398.3	792.8

In the absence of a detailed forest inventory (one is currently underway) and an up-to-date survey of wood consumption, the seriousness of the outlook cannot be precisely stated. It seems possible that per capita fuelwood use may not be as large as has been estimated. Nevertheless, the fact that the wood supply situation is steadily deteriorating is beyond question. Prices for fuelwood have risen substantially in recent years. Commercial fuelwood suppliers to the Banjul, Sere Kunda, and Bakau markets are reaching out as far as 143 kilometers for fuelwood. Thirty-eight percent of The Gambia's needs for sawtimber is met by imports (3).

The Gambia has limited options in this regard. Openshaw stated in 1973 that all of the rural population and 96 percent of the urban households cooked with wood (4). There is no reason to believe the percentages have changed greatly since then or will change significantly in the near future. The idea of switching more of the energy load to fossil fuels, of which The Gambia has none of its own, is not realistic considering The Gambia's growing international trade deficit. During the first eight months of Fiscal Year 1981, the value of imports was seven times larger than exports; when the final figures are in for the year, the trade deficit will probably be about one quarter billion dalasis (Appendix Two).

Nor is it reasonable to meet more of the domestic energy demand with electricity because there is only a small power plant capacity in the country that is losing money despite very high charges to its customers (Appendix Two). The possibility of capturing The Gambia's abundant sunshine to produce solar power on a large scale is yet to be proved feasible. Thus, there appears to be no viable alternative to the forests for meeting household energy needs in the foreseeable future.

Any plants constructed to manufacture modern industrial products such as veneer, plywood, pulp, and particleboard would require relatively low-cost electric power in generous quantities. At the moment, The Gambia cannot meet either of these requirements. The primary producer of electricity in the country is the Gambia Utilities Corporation which operates ten plants that produced 22 million kilowatt hours of electricity in Fiscal Year 1980. In the absence of any hydroelectric potential within the country, all of the output by the corporation has been from diesel-powered generators. The average production cost during that year was 0.43 dalasi per kilowatt hour sold--0.09 dalasi more than the price actually charged for that power. The net loss position of the corporation may be attributed primarily to steadily rising oil prices. More than half the operating cost was for oil. Toward the end of the fiscal year, diesel oil prices took another sharp jump to raise the cost still more (Appendix Two).

The Gambia is thus locked into an electrical system that has no prospect of producing low cost or even reasonable cost power. The limits on doing this may be judged from a prospectus prepared several

years ago for small-scale particleboard plants suitable for developing countries. This prospectus was based on a cost per kilowatt hour of electricity of 3.6 cents U.S. (.069) dalasi. The cost of the electricity sold by the Gambia Utilities Corporation was six times that amount in Fiscal Year 1980.

The Changed Strategy for Managing the Mangroves. The 1980 report, Development of the Gambia River Basin (3), proposed that the Rhizophora mangroves be managed on a 30-year rotation with a 10-year cutting cycle; that is with one-third of the then present stand being removed in each of the next three decades (3). The proposal stated that once the construction of the barrage at Farafenni had been firmly committed, the 8,700 hectares of mangroves upriver from the site should be harvested in a few years. Presumably, cutting and management over the total forest would have been programmed in such a way as to provide a more or less level output of logs during the first 30 years and sustained yield management after that. This proposal, based on a 1978 forest inventory using 1972 aerial photographs, seemed reasonable at the time. It would have permitted any manufacturing plants that might be established for utilizing the mangrove to have a long enough period in which to amortize large capital investments.

As pointed out in Chapter One, such an ideal production-management arrangement is no longer feasible. The extremely high mortality rate of Rhizophora mangrove trees, large and small, during the past several years and the prospect that the high rate of loss will continue requires a change of strategy. It now appears that a very large part of the mangrove stand needs to be liquidated as quickly as feasible and then replanted if the forest is to be adequately restored to a growing condition and the banks of the Gambia River adequately protected. The national timber inventory currently underway will permit more precise judgments in this regard but there is no question that a good part of the present mangrove timber will be lost unless it is cut in the next few years.

This latter fact has profound significance from the standpoint of industrial opportunity. On the basis of what is presently known, it does not seem feasible to build an expensive manufacturing plant requiring a 10, 15, 20 or more year amortization period, considering the rate of loss in the mangrove forest.

Options That Have Been Examined for Utilizing the Mangrove

We have examined various alternatives for utilizing mangrove along the Gambia River. Following is a brief summary of the principal findings and conclusions.

Roof Rafters, Posts, Poles, and Pilings. Mangrove has been used for all of these products. Rhun palm, long favored for roof rafters, is becoming scarcer so demand for mangrove for this purpose should increase, as well as for other pole-type building materials. Protected from the

weather, mangrove has a long service life. There is a local market for poles in The Gambia and the mangroves could be used for this purpose. However, substantial exports would be required to justify a pole treating plant. It is doubtful if mangrove could meet the quality standards of the world utility pole market.

When treated with preservatives, mangrove makes very satisfactory posts for fencing. Since there is a treating plant at Yundum, the potential exists for an expanded domestic market for mangrove posts.

Use of mangrove for all of these round products should be encouraged. However, because the market is limited and small tree sizes are required, these products could utilize only a small part of the potential production of mangrove.

Lumber, Furniture, Flooring, and Specialty Products. Given the high price of imported lumber--300 to 600 dalasis per cubic meter--any opportunity to increase domestic production has much to recommend it. However, it is difficult to season mangrove properly. Uneven air drying, for example, causes serious warping and splitting. Any program to use mangrove for sawn products should include the construction of a kiln so the drying can be done under tightly controlled conditions that will minimize warp and split. The special dry kiln schedules required are not currently available and would need to be developed with the help of outside agencies such as the Forest Products Laboratory in the United States and the Princess Risborough Laboratory in the United Kingdom.

Mangrove has been used to a limited extent elsewhere for flooring. Here again, the development of a local industry would require reliable kiln drying schedules. Mangrove's density assures a long service life in a floor, but that same factor creates nailing problems, thus limiting its utility somewhat. Unlike lumber, specialized machinery, not currently available in The Gambia, would be required.

Much the same can be said about furniture. Correctly seasoned *Rhizophora* mangrove can be made into good quality furniture, but there is still much to be learned about working, finishing, and gluing this wood.

Because of the unknowns, the production of lumber, furniture, and flooring cannot be regarded as ready-made opportunities for using either *Rhizophora* or *Avicennia* mangrove. More technical information and experience is required. The Department of Forestry should begin to explore these opportunities as quickly as its resources permit. A dry kiln should be built, appropriate drying schedules developed, and lumber produced on an experimental basis. Once this problem has been solved, the next move might be to experiment with the use of either or both of these mangroves for furniture manufacture.

Pulp, Plywood, Veneer, and Particleboard. Pulp, plywood, and veneer are consumed in large volumes over most of the world and produced in large, high-investment plants. Mangrove is an excellent raw material for viscose pulp. It is suitable for interior grade veneer and plywood. Nevertheless, these options have to be ruled out for The Gambia. In the first place, pulpwood, veneer, and plywood plants require more electrical energy than The Gambia could possibly supply at this time. In the second place, there is reason to doubt that the existing mangrove timber could be spread over a long enough period to amortize a large capital investment in a factory.

A particleboard plant would have these same problems. In addition, mangrove particleboard is extremely heavy and probably not very marketable in world trade. Moreover, there is apparently an excess of particleboard capacity in the world today.

Activated Charcoal. Although the use of charcoal has been banned in The Gambia, consideration should be given to the manufacture of activated charcoal for export. Because of its density, mangrove makes high quality charcoal. Ordinary charcoal sold for $75 to $100 per ton in 1980 (144 - 192 dalasis). The price has probably risen 15 to 20 percent since then.

Activated charcoal is charcoal that has been specially treated with high temperature gas or steam to remove the volatile materials. For some purposes, the charcoal is pretreated with chemicals. The method of preparation determines the specific adsorbtive characteristics the charcoal will have.

Activated charcoal is used by pharmaceutical and chemical industries as well for special purposes such as water purification and production of vodka. Approximately 90,000 tons of activated charcoal were consumed in the United States in 1980 at prices ranging from $400 to $1,400 per ton (770 to 2,770 dalasis).

Although mangrove is highly suited for the production of activated charcoal and the prices in the world market certainly are tempting, the question remains whether The Gambia could profitably break into this sophisticated market. It is a question that can only be answered by a specialist in the field. The matter is worth pursuing further.

Power Generation. The energy contained in timber in general and mangrove in particular would, under other circumstances, offer a tempting opportunity to bolster The Gambia's infrastructure. Timber could, in the long run, provide a substantial domestic power source to produce electricity required for industrial and other commercial development without aggravating the nation's foreign exchange deficit. In the 1980 fiscal year, 1,614,000 imperial gallons of oil were used by the Gambia Utilities Corporation. Precise comparisons cannot be made because of

the many variables, but we estimate that 20,000 to 33,000 cubic meters of mangrove in a thermal electric plant could have generated the same amount of electricity.

The important point here is that a few thousand hectares of fast-growing timber plantations would be sufficient to sustain--year after year--a thermal electric output equal to the total generated by the Gambia Utilities Corporation in Fiscal Year 1980. This option does not exist at present because of the long time required to make an orderly conversion from diesel powered to steam plants, the rapid deterioration of the mangrove forest, and because today there are only 1,204 hectares of planted forest in all of The Gambia. It has to be considered an idea for the future.

Domestic Fuelwood. While the opportunities for industrial use of the mangrove are presently limited, the need for domestic fuelwood is great. The Gambia is moving toward a fuelwood crisis, as was mentioned earlier. The mangrove can at least bring some degree of temporary relief to the situation. How much long-run benefit will result depends on how well the time that mangrove buys will be used to solve the longer-run wood supply problems.

The fuel for cooking in The Gambia is largely provided by dead trees and branches cut by rural residents for their own use or by commercial cutters for sale in the urban areas. Most of the commercially cut wood is dead keno (*Pterocarpus erinaceus*) which sells at the roadside for one dalasis for a bundle weighing about 11 kilograms (24 pounds). At 50 pounds per air dried cubic foot, this amounts to 74 dalasis per solid cubic meter. This figure, which is in general agreement with other information collected, appears to be a conservative estimate of the cost of fuelwood to the urban householder.

The weight of air-dried mangrove varies according to species and other factors. At 65 pounds per cubic foot, *Rhizophora* mangrove is 30 percent heavier than keno and has 30 percent more heat value. On that basis, one cubic meter of *Rhizophora* mangrove fuelwood is worth 96 dalasis.

In calculating the costs and returns of mangrove fuelwood production in Chapter Six, we have assumed a retail value of 90 dalasis per cubic meter (instead of 96 dalasis), which would represent a reduction in the real cost of home fuel. Even so, it may be difficult to get consumers to accept the idea of paying more than 74 dalasis per cubic meter of fuelwood, even though the fuel value is greater.

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CHAPTER THREE
HARVESTING SYSTEMS

This chapter discusses the alternatives we have considered for harvesting, transporting and handling mangrove fuelwood. It also discusses direct operating costs for producing this fuelwood.

Pertinent Considerations in Developing a Logging System

One of the assignments given our study team was to evaluate different alternatives for logging the mangrove. This charge was predicated on the assumptions that there were several options for utilizing the mangrove timber and that the mangrove might by itself be able to support long-range industrial development. Our terms of reference also implicitly assumed that the mangrove forest was basically a healthy one. This has not proved to be the case. As the preceding chapters have pointed out:

- Mangrove has somewhat limited utility for industrial use;
- The *Rhizophora* forest is deteriorating so rapidly that there is no assurance of a long-term wood supply large enough to justify big investments in plants and machinery; and
- The energy situation in The Gambia is rapidly becoming critical.

These factors combined lead directly to the conclusion that The Gambia's interests would be best served by utilizing the mangrove primarily for fuelwood for home consumption. Smaller amounts of mangrove can and should be used for post, utility poles, building poles and roof rafters. The Department of Forestry should explore the possibility of utilizing some mangrove for lumber. Not withstanding these other uses, the big need and the big immediate market opportunity is for fuelwood. There is little reason, therefore, to bring much timber out as large logs which means it is not necessary to invest in large or moderately large logging machinery. For that reason we have confined our attention to simple and largely manual methods, mechanized only to the extent of using chain saws and outboard motors.

The objective of minimizing capital requirements is further served by the fact that most of the mangrove forest is relatively close to The Gambia River and its bolons. Thus, most of the fuelwood can be transported downriver to the urban areas on barges operated by The Gambia River Transport Company. Only a small part of the mangrove forest is presently accessible by road. Extensive road construction into these swamps would be both costly and environmentally damaging. Thus, there are additional economic and environmental arguments for barge transport.

We have assumed that 80 percent of the wood haul would be by barge and 20 percent by truck. Improved information and actual experience may show that it is not practical to transport as much as 20 percent of the mangrove by truck.

The procedures and cost calculations described in the following pages are based on the following assumptions:

- 100,000 cubic meters of mangrove fuelwood would be produced annually (See Chapter Six).
- First priority in logging would be given to large Rhizophora timber because it is dying rapidly. In the main, the Avicennia timber should be left until later because it does not appear to be suffering heavy loss.
- To facilitate orderly harvesting, cutting blocks should be laid out in advance of any logging.
- All of the logging would be done by contract. Each contractor or cooperating group would have a separate block in which to operate.

Logging the Large Timber

Logging of trees larger than 20 centimeters in diameter typically would involve four steps: falling the trees, bucking them into half-meter lengths, splitting the short lengths into sizes easily carried, then carrying the pieces to the river bank or road and stacking them. Three different types of operation were analyzed -- one using crosscut saws and two using chain saws. Appendix three presents the details of these analyses.

The most efficient arrangement proved to be a two-chainsaw crew consisting of two fallers, two helpers, three splitters and ten packers. Such a crew could produce at least 15 cubic meters of wood a day at a cost of from 12 to 15 dalasis a cubic meter. (Table 3.1)

In the absence of any history of this type of activity in The Gambia, we were obliged to estimate costs on the basis of certain assumptions with regard to operating procedures and productivity. Before undertaking any large-scale wood procurement programs the first step should be to test these assumptions with logging trials in the mangrove swamps to develop realistic productivity estimates as a basis for negotiating contracts. Such logging trials would also provide the opportunity for testing innovations to ease the task, such as for example the use of light weight manually operated hydraulic log splitters.

Since the logging operation proposed is completely different from anything done in The Gambia before, pilot tests are absolutely essential.

Timber falling saws are fairly new to The Gambia, logging traditionally having been done with axes and machetes. Therefore, systematic training in the use of saws, beyond what has already been done along that line, is very necessary. A chain saw, in particular, is a dangerous tool and is more or less fragile in the sense that it is easily damaged. Proper care of chain saws is not easy in a saltwater environment.

Logging The Small Timber

For the present at least it seems desirable to continue to use conventional means -- that is, axes and machetes -- to harvest stands of small trees. In this case a group of men working together would be assigned to a cutting block, presumably with everyone participating in all phases of the work. We estimate that production could be at least four-tenths of a cubic meter per man-day at a cost of 19.5 to 22 dalasis per cubic meter.

Transportation

A number of small boats would have to be acquired to transport most of the loggers between home and work each day. The purchase of these boats and their operation is included in the cost of falling, bucking and stacking.

Barge transportation would require no investment in tugs or barges since all of the necessary floating stock is owned and operated by The Gambia River Transport Company. Further analysis of investment schedules, however, is required. It would be important to negotiate a reasonable barge transportation contract as this is the largest single item of cost which can make or break the whole operation from a financial standpoint.

Most of the wood used in the urban area is now trucked from the forest. We anticipate that some of the trucks could be diverted to hauling mangrove at a contract rate directly to retail dealers or to satellite drying yards and that no new investment in trucks would be required.

At the efficiency levels we have assumed the total cost of loading barges and trucks plus hauling would range from 16.5 dalasis to 22.3 dalasis per solid cubic meter.

A Fuelwood Depot

The biggest capital investment required would be for a fuelwood depot to store wood prior to distribution to retail dealers. Such in-transit storage would be necessary in many cases to allow time for the

wood to dry before being sold. Adequate drying is necessary not only to achieve customer acceptability but as a conservation measure. A certain amount of moisture is desirable so the wood will not burn too rapidly but on the other hand if fuelwood is too wet, heat is wasted in drying the wood itself.

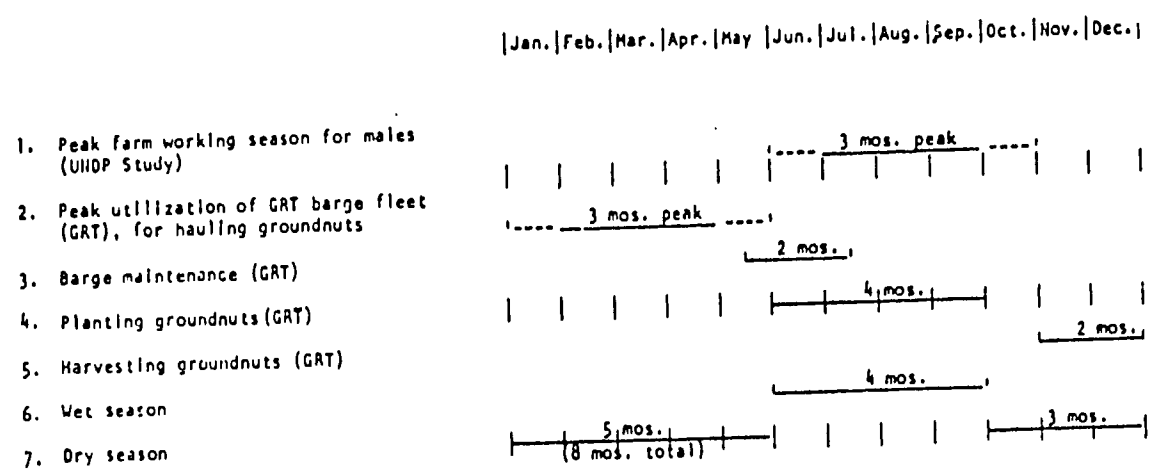
A site near the Denton bridge has been suggested as one possible location for a fuelwood depot. The investment required to provide such a facility is discussed in Chapter Six. Direct operating costs at the depot (including unloading the barges, stacking the fuelwood, loading onto trucks and transporting to retailers) add up to 8.7 dalasis per solid cubic meter of wood.

The Seasonal Nature of Mangrove Production

The schedule for logging and transporting mangrove fuelwood has to be adapted to the seasonal availability of both manpower and barges which are not on the same cycles. The interaction of these two variables results in a widely fluctuating wood output. Also, during parts of the year large inventories of fuelwood would be accumulated along the river and in the depot. Figure 3.1 indicates the peak farm working season and the three months when the barges will be heavily occupied hauling groundnuts.

Figure 3.1

FACTORS THAT DETERMINE THE SEASONAL VARIATIONS IN THE PRODUCTION OF MANGROVE FUELWOOD
(Sources of data shown in parentheses)



During the nine months of the year when farming activity by men is low or minimal October through June, there should be no difficulty in recruiting all of the loggers and associated workers needed. Nor does it appear that the logging operation will have to be completely shut down during the farming season. Some men can be expected to want to log all year long, particularly the more skilled, higher income chain saw operators.

Similarly, it would seem unnecessary to shut down the shipment of fuelwood during the peak period for hauling groundnuts. We have assumed that some older, smaller barges no longer in steady use could be made available to haul fuelwood during February, March and April. Truck transportation of wood should be fairly constant all year long.

Because of the fluctuations in labor and barge availability total employment (logging, loading, unloading, operating the depot) will range from about 350 men in July and August to as many as 1,250 men in December.

For the same reason there could be as much as a three-month supply of fuelwood stacked along the river and the bolons by the end of May. The fact that large quantities of fuelwood would accumulate during the dry season has the advantage of providing time for drying. A critical factor in the success of this operation is the dryness of the delivered firewood. It may be necessary to allow a longer drying period than we have planned for, in which case a larger stock of firewood would have to be maintained in the wood depot. Since most of the wood trucked would be green, it might either have to be sold at a lower price to retailers so they could afford to hold it, or satellite drying yards would have to be established. In either case there would be an additional cost which we have assumed to be 8 dalasis per cubic meter.

Total Direct Costs of Producing Mangrove Fuelwood

Table 3.1 summarizes our calculations of direct costs of producing mangrove fuelwood and delivering it to market under several different situations. The weighted average cost is 44.0 dalasis per solid cubic meter of mangrove. An overall analysis of costs and returns, including indirect costs, is contained in Chapter Six.

Table 3.1

ANTICIPATED DIRECT COSTS OF PRODUCING AND DELIVERING MANGROVE FUELWOOD UNDER DIFFERENT LOGGING AND TRANSPORTATION METHODS

	Transported by Barge (80%)		Transported by Truck (20%)	
	Largewood 1/ 70%	Smallwood 2/ 30%	Largewood 70%	Smallwood 30%
	-- dalasis per cubic meter --			
Felling, bucking, stacking	12.0	19.5	10.0	17.0
Transport to roadside	-	-	5.0	5.0
Barge or truck loading	2.3	2.3	1.5	1.5
Transportation	20.0	17.5	15.0	15.0
Unloading barges and stacking wood	1.5	1.5	-	-
Other Storage Yard Costs	2.4	2.4	-	-
Truck loading and transport to retail yard	5.0	5.0	-	-
Additional Cost Related to Drying			8.0	8.0
Total Direct Cost to Retail Yards 3/	43.2	43.2	39.5	46.5

1/ Stems of trees larger than 20 centimeters in diameter.
2/ Tops of all trees and stems of trees 20 centimeters in diameter and smaller.
3/ See Chapter Six for total costs.

CHAPTER FOUR
INSTITUTIONAL INFRASTRUCTURE AND MANPOWER MOBILIZATION

This chapter discusses the institutional infrastructure required for successful utilization and management of the mangrove forest. It also discusses factors relating to the mobilization of an adequate working force.

Infrastructure

Management of the production process outlined in Chapter Three will impose heavy new responsibilities on the Department of Forestry, already understaffed and thinly spread. In addition, the Government of The Gambia may wish to consider a special institutional arrangement to facilitate the production operation.

The Department of Forestry. The Department of Forestry would certainly have to develop the staff and capability to monitor what is going on as it relates to timber growing and protection of the environment as well as to make the multitude of forestry decisions required. This would involve supervising planting programs to be discussed in Chapter Five. The Department would also need to assume responsibility for selecting and demarking cutting blocks, a task that would be facilitated by the October 1980 aerial photographs and maps drawn to a scale of 1:50,000. In the reaches of the Gambia River where bolons are numerous, cutting zones could be demarcated by a system of coding; for example, a single mangrove cutting zone could be the area bounded by bolon B-1 and B-2. In the lower regions, brightly colored plastic flagging ribbons can be tied to prop roots or poles driven into the mud.

Administrative Organization. Some special arrangement would need to be made to handle production aspects of the program outlined in Chapter Three. The more immediate problems of assuring an adequate food supply and improving the health of the present population have drawn so heavily upon the attention and resources of The Gambia that there has been little effort left to deal with the longer range timber supply problem. If this situation is to be changed, it probably will be necessary to separate responsibility for timber production from the normal functioning of government. This idea may already be under consideration, as it was raised in the recent report Forests and Forestry in The Sahel - The Gambia--A Case Study. The report suggested that a forest products marketing board be established as a quasi-public corporation. The Gambia Produce Marketing Board, which deals with agricultural products, is an illustration of an existing organization that carries out functions parallel to those required for the mangrove operation.

Such a marketing board could assume responsibility for utilizing mangrove as a money-making activity, in addition to providing needed fuelwood to urban communities. At the same time, it could begin an extensive

tree planting program elsewhere as quickly as site classification, species selection, and financial analyses permit. The sale of mangrove would, hopefully, provide some money needed for establishing village and larger plantations.

Regardless of the administrative setup chosen, a special organization would be required to handle management, accounting, disbursements, sales, administration and security involved in a mangrove utilization and management project. Among other things, the staff would:

- Tally the wood received from all incoming barges and trucks.
- Compare quantities received with quantities reported as loaded at stacking points by the contractor and amounts discharged at the depot as reported by The Gambia River Transport Company supervisors.
- Report any discrepancies to The Department of Forestry and The Gambia River Transport Company.
- Maintain an inventory at the depot at the beginning of the year equivalent to two months' production (about 17,000 cubic meters. This would be a cushion against future shortages during slowdown of barging.
- Arrange for prompt payments to contractors engaged in harvesting mangroves. Falling, bucking, splitting, stacking, and loading could be contracted; village chiefs could become contractors if they wished. Prompt payment would assure enthusiastic performance and avoid a turnover of trained personnel.
- Provide the needed security measures such as a 24-hour guard service at the depot, a periodic river bank patrol to watch fuelwood stacked on the bank. Police at road checkpoints could be asked to verify credentials of truckers carrying wood into the Banjul area.
- Maintain radio liaison with field supervisors (to confirm progress in cutting and stacking) and liaison with tugs operating upriver (to coordinate unloading of fuelwood).

A general outline of what a mangrove marketing operation might include is illustrated by Figure 4.1 in the form of an organogram. Main responsibilities of the key components in the operation are listed below.

Forest Products Marketing Board Responsibilities

1. General management and supervision of harvesting and marketing operations.

   a. contract harvesting operations;

   b. manage mangrove depot;

   c. supervise and control sale of mangrove to retailers;

2. Support further studies and research on uses of mangrove.

Department of Forestry Responsibilities

1. Demarcate areas for harvesting.

2. Supervise cutting and environmental practices in connection with the mangrove harvest.

3. Supervise replanting of harvested areas.

4. Supervise and monitor tree planting field trials.

5. Conduct studies related to continuing management of the river front forest.

GPMB (GRT) Responsibilities

1. Transport mangrove wood to depot; load and unload barges.

2. Coordinate hauling of mangrove to depot.

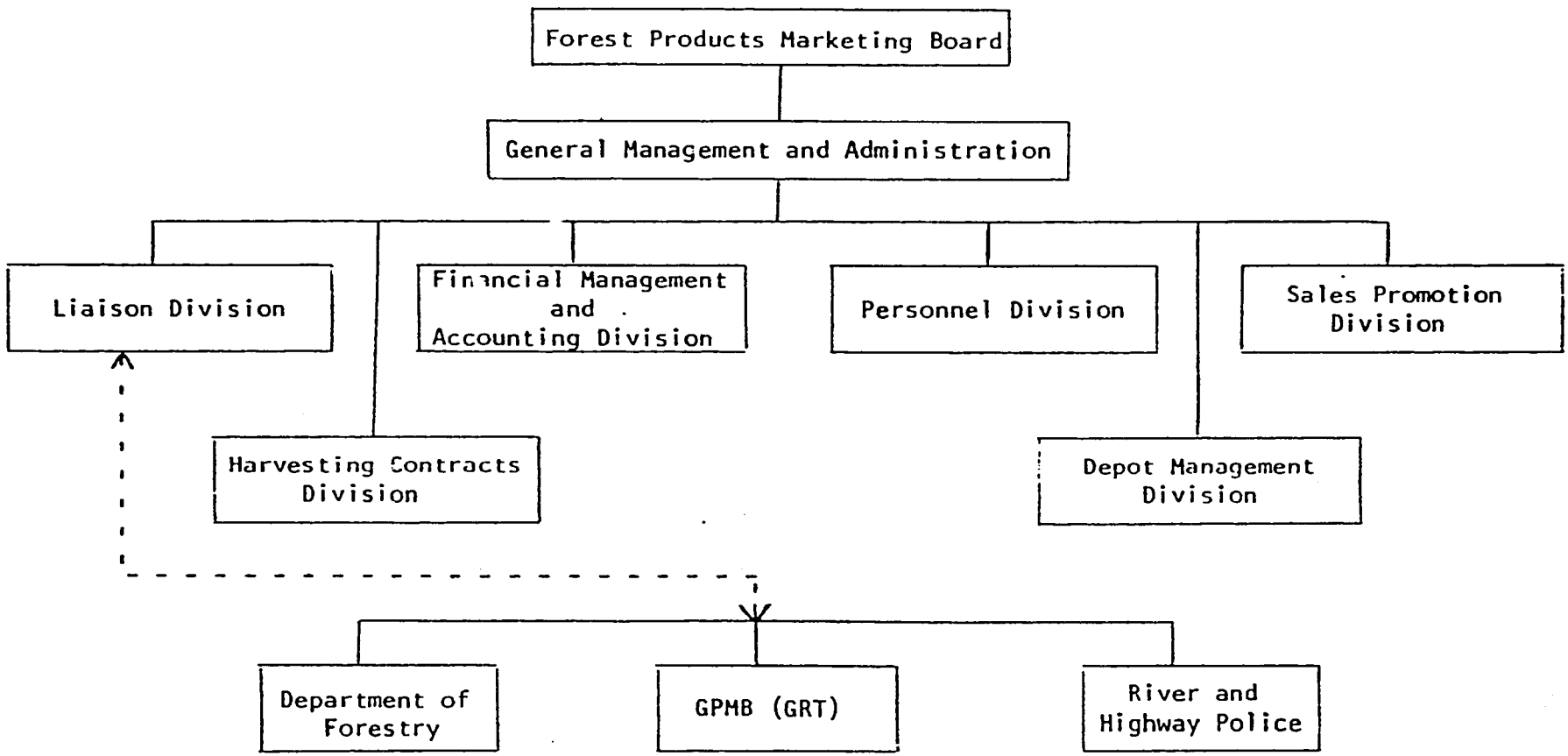
River and Highway Police Responsibilities

1. Patrol river to prevent stealing of stacked wood.

2. Check credentials of truckers hauling wood.

Figure 4.1

MANGROVE HARVESTING AND MARKETING OPERATION ORGANOGRAM



Mobilizing the Work Force

As pointed out in Chapter Three, we foresee no problem in meeting anticipated labor requirements. Even during the peak farming period, there are people in search of employment (1,2). Our conclusion that there should be no difficulty in recruiting workers is supported by the opinions of others:

- The Freedom from Hunger (FFH) project (also known as the Action for Development, German Committee) has been in operation for over five years. One principal activity of the FFH project has been management of a program to improve the production of rice. This has included building of dikes, causeways, access roads, and irrigation ditches. In 1976 through 1980, the FFH project hired 1,500 workmen each year and in 1981, hired 800. There were no difficulties in finding workmen willing to engage in the hard physical labor involved in return for payments partly in cash and partly in food, amounting to a total value of D3.78 a day in 1981. In fact, applicants for this work were usually twice the number of available jobs (7).

- Officials interviewed by our study team--in the Public Works Department, Department of Forestry, Gambia River Transport Co., Ltd., Gambia Produce Marketing Board, District Commissioners Office in Farafenni, four work crew foremen supervising road repairs between Farafenni and Soma--were unanimous and categorical in stating that workmen for mangrove harvesting would be available when needed.

- There are contractors specializing in mobilizing labor for major projects in the Farafenni-Soma area (for example, Bakanding, Camara, Suwaro Gasama, Malang, Yaya Marong, Jang Gassama, Sorsi Sedi, and Momodou Dabbo).

- Groundnut exports in 1980 declined to 21,300 tons from 53,590 tons in 1979, tourism has declined, many young men are abandoning farms in the hope of finding nonfarm jobs. Because The Gambia has entered a period of economic recession, there is a surplus of people looking for employment. Calculations in Chapter Three assume that unskilled members of harvesting crews would earn higher than minimum wages because of the difficult working conditions.

There are, however, projects planned that could create substantial additional labor requirements. The UNDP has proposed a forestry project that could require 10,000 to 13,000 people by the end of the century (6). Barrage construction at Yelitenda may employ 1,500 workers. Double cropping on 22,400 hectares above the barrage would provide additional employment in the dry season (8). However, the total labor force is growing.

There seems to be no tribal, caste, religious, or other social factors that would interfere with mangrove harvesting as proposed in this report (3, 2).

There will be no problem in handling of smallwood which will be cut by machete and axe (Chapter Three). The Pioneer Unit near Farafenni and the Department of Forestry have had experience with chain saws. From the experience of the Pioneer Unit (3) and the Department of Forestry (19), Gambian crews have demonstrated ability to operate chain saws, as done now on a limited scale. However, six to eight weeks training would be needed in the operation and maintenance of chain saws. Initial logging operations will need to be supervised closely to avoid hazardous practices, assure selection of trees that can be feasibly felled, and assure selection of trees which can yield good quality fuelwood.

People trained to become skilled loggers will probably want to own saws and other tools. This is almost a necessity to assure that these tools are properly cared for and have maximum service life. A loan program would be required to finance the purchase of these tools at least during the first few years (Chapter Six).

There are at least three options available for providing the training of harvesting crews. The first option is to send the prospective harvesting crews to training centers. If the first option is selected, the following locations, most of which are near Farafenni, could be considered:

- The Pioneer Unit at Farafenni which currently trains people in the operation of equipment such as chain saws;
- The Anglican Vocational Training Center which would be available during school holidays at Farafenni;
- The Gambian Opportunities Industrialization Center (GOIC) near Farafenni;
- The Community Development Center at Mansa Konko; and
- The future training center to be established for mechanics and construction workers by the World Bank.

A second option is to have training teams go to the villages. The FAO training expert interviewed suggested that two-man training teams should be organized consisting of a Forestry Agent and a forestry volunteer (e.g., a Peace Corps Volunteer). These teams should then visit villages to demonstrate and train candidates for the falling crews. This method of training would, the FAO expert thought, expedite and expand the transfer of technology.

The third and probably most feasible alternative is to train on site, i.e., in the mangrove swamps. This is because mangrove conditions are unique and field experience in the swamps is critical to efficient harvesting operations. Actually, such on-site training should probably be preceded by one of the other two training programs.

Literature regarding The Gambia stresses the importance of coordinating any form of economic activity in rural areas with local leaders (2, 5, 9, 21, 22).

Nutrition and Health

There is already a high incidence of malaria (2); the diet of most Gambians is deficient in calories, protein, and B vitamins (1, 27, 28). Once the barrage is built, it is to be expected that some diseases such as schistosomiasis will increase and malaria will become more widespread.

The mangrove harvesting program will increase the number of skin infections, cuts, and serious accidents because of the hazards of falling trees on uneven and sometimes unstable ground. These factors suggest the future need for more facilities to care for persons injured.

Land Tenure

Most of the mangrove trees are standing on land that is not in use, is unclaimed, and has not been cleared for agriculture. It was the consensus of Department of Forestry officials and village authorities that areas covered by mangrove forests could be cut and planted without running into claims of land tendure that would impede efforts.

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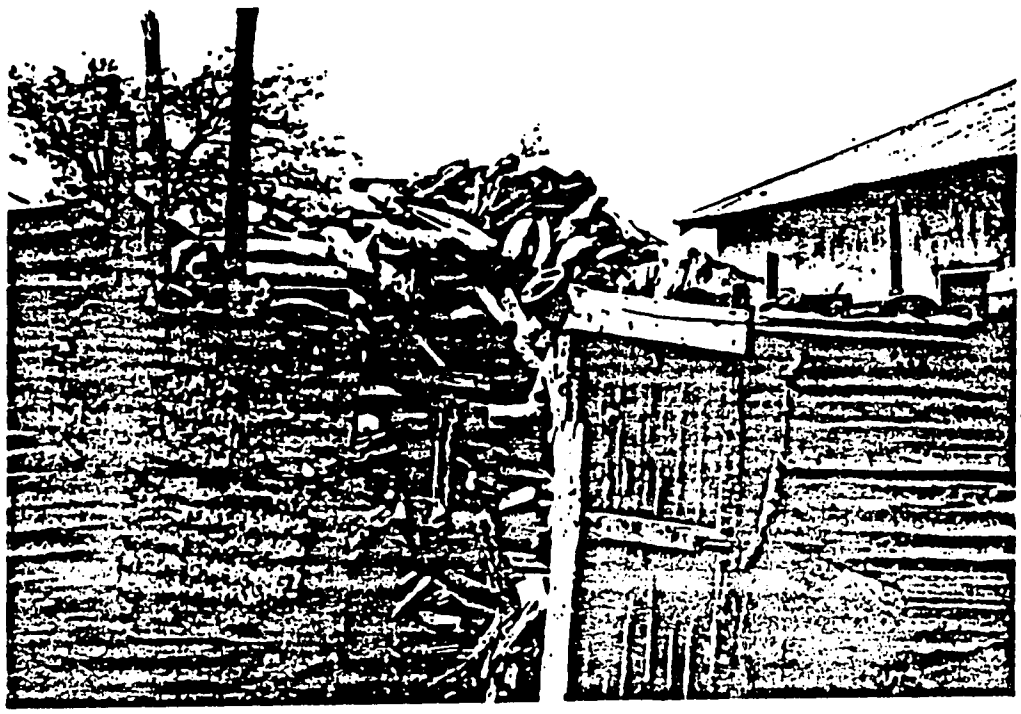
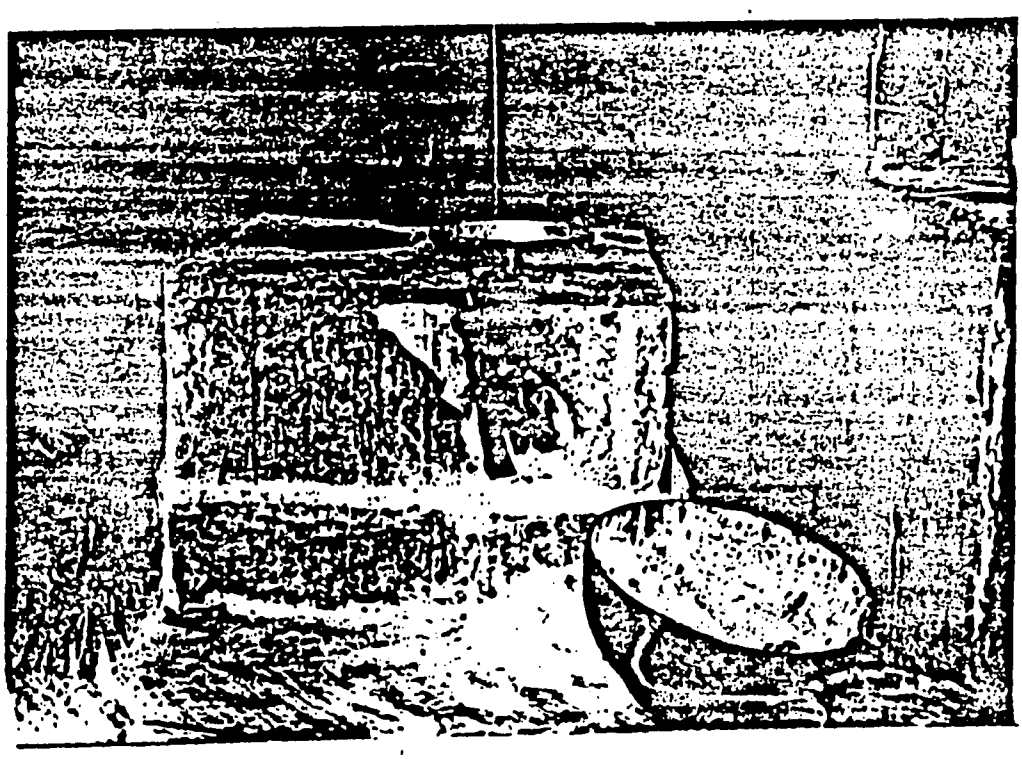
4. Upland wood is cut by woodcutters--143 km from Banjul.

5. When cut, wood may be bundled and stacked on the roadside for immediate sale.



6. Upland wood is brought to retailer outlets such as this one of 13 in Bakau.



7. Cooking is generally done on low, open fires. Recently the Department of Forestry has introduced fuel-efficient stoves.

CHAPTER FIVE
ENVIRONMENTAL ASPECTS OF MANGROVE UTILIZATION

This chapter discusses the environment in which mangroves are found in The Gambia, changes that could result from harvesting operations and measures necessary to protect the environment once harvesting operations begin. Second, the chapter discusses the rehabilitation of harvested areas to protect shorelines and continue wood production.

The mangroves of The Gambia include three species of Rhizophora (red mangrove or mankwo), Avicennia africana (black mangrove or Jumbukungo), and Laguncularia racemosa (white mangrove or batamanko). Rhizophora racemosa and Avicennia africana are the predominant species as far as wood volume is concerned.

Mangrove Distribution and Salinity

As with other plants, the survival of mangroves is influenced by ecological conditions: soil, water quality, light, disease, insects, and so on. As these conditions change they affect the life of the plant. Since factors affecting the ecology along the river differ, vegetation forms differ too, and so does distribution of mangrove. Salt water is a key factor in distribution of mangroves, and while they are commonly associated with it, mangroves do not appear to require salt water. They compete successfully in the saline tidal areas because most other plants do not do well in such an environment. In non-saline waters or where they become seeded upland, they are poor competitors, probably because they grow slowly and are shaded out by faster growing freshwater hydrophytic or upland species(1). Nevertheless, some mangrove genera such as Avicennia are rarely found growing in waters of low salinity; others, such as Rhizophora mangle, grow better in salt or brackish water than in fresh water (2).

Maps prepared in 1980 by LRDC and Johnson's report (3), show that the Gambia River mangroves range from predominantly small trees less than 7 meters high near the river mouth to trees taller than 20 meters upriver from Tankular. Tall stands of mangrove, Rhizophora racemosa, frequently occur between Tankular and Elephant Island. The width of Rhizophora mangrove stands and their height both decrease upriver from Elephant Island. Avicennia trees were found no farther upriver than Dankunku Island, 167 kilometers upstream. Large Rhizophora racemosa were found in small stands on Pappa Island, 193 Kilometers upriver, and small Rhizophora racemosa were found upriver at Nianimaro (217 kilometers) but not at Kuntaur (230 kilometers).

The occurance of Rhizophora and Avicennia mangroves and other species as a function of salinity are shown in Table 5.1.

Tall Rhizophora racemosa do not occur at high salinities near the river mouth; Avicennia are not found where there are maximum annual salinities of less than 18 parts per thousand. Tall Rhizophora racemosa do not grow at maximum salinities below about 18 parts per thousand, and only a few small Rhizophora racemosa occur when the water is fresh all year.

In the present natural state, salinity in the river decreases from its mouth upriver (See Table 5.1). From Elephant Island upriver shorelines are increasingly bordered by dense prairies of Phragmites which is tolerant of brackish water. The acacia-like shrub, Drepanocarpus lunatus, is more frequently seen as are dwarfed Phoenix palms. Farther upriver, freshwater grasses and palms increase while mangroves (Rhizophora racemosa) become smaller and disappear between Nianimaro and Kuntaur. In this area, several "grassy" species appear, such as Cyperus, Echinochloa, and Typha; at the river bank or a short distance inland are Borassus, Elaeis, Phoenix, and Raphia palms. Coode and Partners reported (5) that Pandanus grows farther upriver and that it has roots which collect silt and help to stabilize river banks.

Soils

Soils of the Bàmba and Yelitenda series in the area above the proposed barrage from Yelitenda to Dankunku Island are particularly important to mangroves, as well as other vegetation and animal life, because they are sulfidic. When exposed to air for prolonged periods, they become extremely acid, with pH's falling to between 2 and 3. According to Thomas, et al (4) who studied the situation, just how serious acidification may be cannot be predicted without more detailed field study, but the strength of acid and its concentration have been suggested as capable of killing mangroves as well as other plants and animals.

Another characteristic of soils relevant to mangrove utilization is that they differ in their ability to support weight. For example, they may be soft, "unripe" wet muds or firmer, "half-ripe" soils or more mature, better-drained "ripe" soils. Unripe soils are so soft that they will not support the weight of a person unless roots are present; half-ripe soils can support light machinery; ripe soils can support heavy equipment (4).

The nature of these soils is such that they erode easily if not protected by vegetation such as the root mats of mangroves. If attention is not given to protecting banks during harvesting to the maximum extent possible, banks will slump and erode, resulting in siltation of the reservoir and channels.

Table 5.1

OCCURRENCE OF MANGROVES AND OTHER PLANTS ALONG THE LOWER GAMBIA RIVER IN RELATION TO SALINITY

Location	Distance from River Mouth (km)	Mangroves				Observed Non-Mangrove Plants Along River	Salinity of River*	
		Small Rhizophora (< 7 m)	Medium Rhizophora (>7-20 m)	Tall Rhizophora (> 20 m)	Avicennia		Annual Maximum	Annual Minimum
							Parts per Thousand	
River Mouth, Banjul	0	✓	-	-	✓	-	38	24
Tankular	44	✓	✓	✓	✓	-	35	4
Tendaba	100	✓	✓	✓	✓	-	29	1
Elephant Island	150	✓	✓	✓	✓	occasional reeds	21	0
Dankunku Island	167	✓	✓	✓	✓	reeds, palms, sedges	18	0
Pappa Island	193	✓	✓	-	-	reeds, palms, Drepanocarpus, sedges	10	0
Nianimaro	217	✓	-	-	-	reeds, several palms, Drepanocarpus	1	0
Kuntaur	230	-	-	-	-	reeds and a variety of grasses	0	0

* Data from Scheffers (7), Hydromet and field measurements during May-June 1981.

Wildlife Protection

Harvesting operations extended over a number of years and cutting in blocks along the river and bolons, as described in Chapter Three, would leave sufficient habitat undisturbed at any one time to avoid adverse effects on the birds and other wildlife.

Changes Due to Permanent Freshwater Environment

When the barrage is operational, water upstream from Yelitenda will be fresh all year instead of brackish during the dry season. The plant species that will become established initially in the present mangrove zone above the barrage after it is operating will probably be those with some tolerance of salinity, such as the *Phragmites*, *Drepanocarpus*, and *Phoenix* and *Raphia* palms. Over the long run, conditions above the barrage will be favorable for freshwater floodplain grasses because of the permanent freshwater environment.

Stabilizing the Banks of the River and Its Bolons

When a *Rhizophora* mangrove tree is felled its roots die and lose their ability to hold the soil. Thus, the cutting of mangroves along the banks of the river and bolons can be expected to lead to erosion of the unripe and half-ripe mangrove soils. In Thailand it has been recommended that at harvest time an uncut band of mangroves 10 meters wide be left along the banks of streams and canals to assure bank stability. However, leaving an uncut band of mangroves along the banks in The Gambia cannot be relied upon to provide long-term bank stabilization because of the widespread occurrence of the dieback disease which threatens to eliminate most of the trees. What needs to be done differs above and below the proposed barrage site.

Below the barrage site salinity conditions are not likely to be changed by the construction of the barrage. Here, there will continue to be some natural regeneration. However, because of the heavy loss of older trees the reseeding is likely to be spotty. Natural regeneration should, therefore, be supplemented with hand planted mangrove propagules. Recommended spacing, seed sources and cost estimates for hand planting *Rhizophora* are listed in Appendix 5. Too little is known about *Avicennia* to recommend a planting program. Bank stabilization would be enhanced by planting *Rhizophora* propagules 1-2 years before harvesting the trees in those places where the canopy is open enough (i.e., not too much shade) for them to grow. Where planting in advance of cutting is not possible, it should be done immediately after logging.

Above the barrage site, bank stabilization will have two phases. Until the barrage is built, the banks of the river and bolons from Elephant Island downriver to the proposed barrage site should be replanted with *Rhizophora* propagules immediately after mangrove

harvesting to provide temporary bank stabilization. After the barrage has been built and th soil salinity in this region sufficiently reduced, freshwater tree species may be planted that would aid in bank stabilization as well as provide a firewood crop.

Upriver from Elephant Island the water is progressively less saline and there is a little likelihood of planted mangrove propagules growing well enough to stabilize the banks. In this region reeds, palms and shrubs will probably invade the areas where mangroves are cut. However, these plants may be useful in bank stabilization. If a forest cover is to be maintained along the rivers edge above the barrage, a second planting will have to be done with species that will grow under conditions of seasonal flooding. At present the brackish water extends upriver more than 80 km from the proposed barrage site at Yelitenda. Because of the consequent soil salinity, mangrove soils under freshwater conditions will not be suitable for field testing tree species for mangrove replacement until after the barrage is in place and the soils above it have been leached for a year or more. Three species that grow on wet or flooded soils and that might be suitable firewood crops are: Thespesia populnea, the seaside mahoe; Melaleuca leucadendron, the cajeput; and Acacia nilotica, the Egyptian thorn (6).

When the barrage is in operation, evaporation from the impounded water is expected to exceed the river flow from mid-December to mid- June (5). It is important not to exacerbate that problem with excessive transpiration from vegetation. If the mangroves are replaced by reeds and grasses, water losses due to evapotranspiration may be greater than those calculated by Coode and Partners. Transpiration losses would be less if productive trees replaced the nearly worthless reeds and grasses.

Effects of the Dieback Disease on Regeneration and Rehabilitation

The dieback disease does not seem to affect seedlings during the first year. Many small Rhizophora trees were seen that appeared to "stay ahead" of the disease by developing new prop roots to replace the diseased ones. Whether such 2-3 meter high trees are actually resistant to the disease is not known.

Because of the reduced disease effect on young Rhizophora trees, planted propagules might grow sufficiently during the first few years to stabilize the river and bolon banks, but be affected by the disease and as a consequence not produce a suitable wood yield in later years. Because of the possibility that the dieback disease is a permanent feature of Rhizophora mangroves in the Gambia, species of mangroves from other parts of the world might be introduced and tested for disease resistance and firewood production potential. Mangroves species that might be suitable include the following genera: Bruguiera, Ceriops, Kandelia, Sonneratia, Lumnitzera, Heritiera, Pelliciera, and Xylocarpus.

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CHAPTER SIX
FINANCIAL PROSPECTS

This chapter discusses financial feasibility of a program to harvest, process, and market mangroves and the financial support required. It describes some factors to include in organizing and managing such a program.

Objectives

We believe commercial fuelwood operations should:

- Keep delivered costs of fuelwood to urban households at or below present levels.
- Keep capital requirements for commercial operations at a minimum and depend on labor-intensive rather than capital-intensive systems to maximize employment.
- Rely on private individuals and companies to handle as much of the total production process as possible.
- Return a profit for reinvestment in timber growing.
- Log high disease risk stands first, to save as much timber as possible for later utilization.
- Restock the present mangrove shoreline with seedlings wherever necessary to assure continued production and protection of the environment.

Project Life

As Chapter One indicates, we estimated that without logging, 2.4 million cubic meters of mangrove will be left in 1986. Between 1978 and 1981, economic loss resulting from mangrove mortality amounted to more than 70 million dalasis. If *Rhizophora* mangroves are not salvaged, The Gambia will incur an additional economic loss of at least 65 million dalasis, based on retail values.

No one can be sure if even 2.4 million cubic meters of mangrove will be available for use in 1986. Because of the rate at which *Rhizophora* mangroves are being killed by disease, a major portion of the utilizable volume of this genus may be lost in as few as five years. The "worst view" may be wrong, but it cannot be ruled out because losses are occurring rapidly (see Chapter One). For this reason, the effort

during the first five years should be to salvage Rhizophora timber that would otherwise be lost. Only those Avicennia within the Rhizophora stands should be logged during this period. Once salvage operations are complete, cutting should be on a sustained yield basis--heavily dependent on Avicennia during the years the riverbank species are being reestablished. What the sustainable production of the mangrove forest may eventually be, we don't know. This is something that needs to be determined by further study.

During the first five years when the salvage operation is underway, annual timber cut should probably be about 100,000 cubic meters. This appears to be the maximum feasible because that amount appears to be about all the fuelwood the urban market could absorb in any one year. Though available estimates suggest that urban households are consuming 171,000 cubic meters of fuelwood annually, there has been some question as to whether that figure is too high. The market should not be expected to absorb more than 100,000 cubic meters of mangrove fuelwood annually even if supplies from upland areas are restricted, as will be necessary.

Storage of wood for a number of years at an extra expense, if supply exceeds demand, is possible. However, since the transportation system is a second limiting factor, it is doubtful if more than 100,000 cubic meters of mangrove could be delivered to the urban areas of Banjul, Sere Kunda, Bakau, and Brikama because not enough barges are operated by the Gambia River Transport Company. These barges would be the primary means of bringing mangrove wood from swamp to market. The barge system was established to haul groundnuts. For that reason, it has limited capacity for wood hauling from January through May. During other months, the barges are largely unused.

In recognition of the constraints mentioned above, the best strategy might be to establish a commercial operation delivering 100,000 cubic meters each year for five years, continuing at a lower sustainable level after that. In addition, fuelwood could be sold at the river bank during the first five years for export at a profit to The Gambia. To the extent that a substantial external market develops, logging operations could be expanded accordingly. Furthermore, rural families and others wishing to cut their own mangrove fuelwood and other products could be encouraged to do so for a nominal stumpage fee, under appropriate supervision by the Department of Forestry.

Capital Requirements

In order to carry an operation of this nature, establishment of a fund of 3.5 million dalasis would be required to handle the items listed below:

Loan fund for chain saws and other logging tools (since all of the mangrove will be logged as fuelwood, it will not be necessary to invest in expensive logging machinery).	D 220,000
Loan fund for boats and motors for moving crews	D 400,000
Installation of a wood depot along with associated facilities and equipment	D 450,000
Revolving fund for advance payments to logging and hauling contractors for fuelwood stacked along the river bank and stored at the wood depot for extended periods	D 600,000
Salaries of supervisors and related costs	D1,000,000
Mangrove planting and replanting	D 430,000
Added for contingencies	D 400,000
	D3,500,000

The money for logging equipment, boats, and motors would be converted into loans for contractors to purchase those items. Loan repayment plus 10 percent annual interest are part of the logging costs discussed later. The 600,000 dalasi revolving fund to pay for wood in storage would constitute no charge against the mangrove produced because once the operation is completed, the fund could be returned to its original source intact. All other capital expenditures are included in the production and handling costs discussed below, the total investment being amortized in five years.

Sources of Financing

We believe that the deterioration of the mangrove resource is of such a critical nature as to justify emergency financing. The Gambia's nearly total dependence on wood for cooking, coupled with the extremely rapid rate of loss of mangrove timber, create an unquestionable urgency for salvaging dead and dying trees. Necessary financing might be sought through an amendment to the USAID Gambian forestry project or from other donors. In any case, immediate action is required.

Profitability

Assuming the average price to households would be 90 dalasis per solid cubic meter of fuelwood (Chapter Two), cost figures are estimated as follows:

Table 6.1

ESTIMATED TOTAL FUELWOOD PRODUCTION COSTS
FROM MANGROVE TIMBER

	Dalasis per Solid Cubic Meter
Direct operating costs from stump to retailer (Chapter Three)	44.0
Capital cost of wood depot	0.9
Planting (Appendix Five)	0.9
Supervision and contingency	2.8
Stumpage fee	10.0
Margin for profit and risk	11.4
Cost to retailer	70.0
Retail mark-up	20.0
Price to households (Chapter Two)	90.0

The cost figures presented above assume that the logging and transportation to the fuelwood depot would be contracted. Unloading at the depot and handling in the depot could be done by hired workers. Transportation from the depot to retail yards could be contracted. Some costs may be reduced below these figures through negotiation.

A 10 dalasi stumpage charge is included above on the assumption that it could be effectively used to staff and equip the Department of Forestry to meet its substantial responsibilities in managing the mangrove forest. Without such leadership, much damage can be done to that forest.

CHAPTER SEVEN
INTEGRATION OF A MANGROVE PROGRAM INTO THE ECONOMY

This chapter discusses integration of a mangrove management and development program with Gambia forestry and Gambia river basin development programs in the context of the Gambian economy. The chapter also includes an assessment of impact on rural and urban poor.

The Gambia Forestry Program

Previous chapters in this report have drawn attention to the critical importance of wood to the Gambian economy. Some analysts have noted that at the present rate of consumption, The Gambia may be approaching the end of its wood supply by the year 2000. Although these estimates need verification, programs to do something about the supply nevertheless deserve high priority in national development objectives.

The Gambia forestry program described in Forests and Forestry in the Sahel (1) cites 13 forestry sector development strategies as steps to be taken between 1981 and 1986 toward achieving national forest objectives. A mangrove management program of the type outlined in our report is directly related to several of the strategies. For example, the ongoing national forest inventory includes mangroves; research on species/site trials has been recognized as necessary in recovery and rehabilitation of harvested mangrove areas; a forest products marketing board has been discussed in the Sahel report as a potential institutional arrangement for a mangrove harvesting and marketing program; training for both skilled loggers and hand-tool users has been noted as essential to safe and efficient harvesting operations; wood-burning stoves have been mentioned in connection with mangrove use; and the Department of Forestry has been identified as the agency to, at a minimum, be responsible for technical supervision and regulation of on-site harvesting operations.

It is obvious that the mangrove management activities described in this report are closely tied and can be integrated into ongoing and planned forestry programs in the near future. But in addition, integration of a mangrove program with other ongoing economic development activities in The Gambia has to be taken into account: for example, activities related to the agricultural planting and harvesting cycle; mobilization of labor force; availability, capacity, and scheduling of barges; and activities of wood producers, retailers, and wood users. Thus, not only can a mangrove management program be integrated into forestry programs--with some significant adjustments in manpower and resources as discussed in Chapter Four--but into other sectors of the economy as well.

Gambia River Basin Development Program

Based on reports prepared by the United Nations Development Programme multidisciplinary-multidonor mission report, forestry programs in the basin are expected to reverse forest land depletion and to achieve long-term national self-sufficiency in forest products (2). Approaches to forestry development in the report include three alternatives: the first is labor intensive, and relies on use of hand tools and limited mechanization; government forestry agencies; private wood suppliers; and producer forestry cooperatives.

A second approach they present would rely on comprehensive mechanization of forestry operations, including chain saws, mechanical splitters, light tractors, and small-scale motor power. The latter include capital intensive logging of Gambian mangroves.

A third alternative combines the above two; it would:

- introduce the management of natural forests;
- campaign against bush fires;
- establish a plantation program using fast-growing tree species;
- exploit the mangroves upstream from the salinity barrage before they are wasted;
- begin management of the mangrove forests downstream from the damsite;
- reduce the reliance on charcoal as a domestic fuel;
- introduce and promote the use of alternative energy sources, e.g., butane gas, mineral coal, agricultural wastes, biogas, and solar energy; and
- reduce fuelwood consumption by the design and promotion of more efficient wood-burning stoves.

Reference to mangroves in the above report is out-dated by recent findings. The management strategy described therein will of course need to be revised to account for current conditions. Exploitation of mangroves above the barrage before wastage, discussed in the UNDP report, is also accounted for in our report as is management of mangrove forests downstream from the damsite. However, any need for highly mechanized logging has been largely removed by recent changes in the forest situation and outlook for markets as discussed in the preceding chapters.

Impact on the Urban and Rural Poor

There will be an adverse impact on nutrition of the poor should a shortage of fuelwood reach the point where foods presently cooked are eaten uncooked. FAO and other nutrition studies point out that Gambians have a diet deficiency insofar as caloric intake is concerned. This is especially true for pregnant women and weaning babies. Infectious and diarrheal diseases are prevalent among Gambian children (2). These problems can be aggravated when foods are not cooked. Cooking kills parasites and combats the anti-nutrients in many raw foods (3). There is much to be learned about the relationship of cooking to the nutrient value of foods, but there is no doubt that the human digestive system is adapted to cooked foods and nutrition will suffer in the absence of cooking. Fuelwood for cooking is not merely a convenience. It is also an important part of the process of providing an adequate diet.

Economic Impact

In planning for the marketing of mangrove in urban areas, a number of factors must be taken into account, including the existing price structure and the impact of a potentially large supply of fuelwood on the commercial market and thus indirectly on all those in the production chain. At present, the Department of Forestry is using its influence to keep the price of commercially produced fuelwood from becoming too high. Introduction of large volumes of mangrove fuelwood into the urban markets might not cause any change in price if it merely replaced fuelwood from upland areas. However, if the flow of wood from the uplands were not reduced by an amount corresponding to the increase in mangrove production, prices could be expected to fall to the benefit of urban consumers, but probably at the loss of financial solvency to the producing institution and lower income to those on the production chain. If the program described in preceding chapters is adopted, the marketing process should be handled in such a way as to keep fuelwood prices stable, at a level no higher than at present.

In rural areas, fuelwood is largely a free good, obtained by individuals foraging for deadwood for their own use. Rural poor close to the river certainly should benefit in the short term if they take advantage of the opportunity to cut their own wood in the mangrove forest. In the long term, they would benefit from the respite given the upland forest and such gains in productivity as result from that respite. Those close to the Gambia River would benefit to the extent that stepped-up management efforts provide additional environmental safeguards, especially as they relate to fisheries. Rural poor farthest from the mangrove supplies would benefit only indirectly by reduced drain on local wood resources occasioned by decreased cutting of upland woodlands to supply urban needs.

The Long Range Contribution of Mangrove Timber

In this report, we have suggested a short-range salvage operation calculated to be profit producing in addition to providing much needed fuelwood. But this need not be the end of the story. After the first five years, there may have to be a temporary reduction in the timber cut--maybe not. The wide range of productivity in mangrove areas as related to species, soil, salinity, land levels, and a complexity of other factors make it impossible to predict future yield possibilities with our present state of knowledge. The question of whether the disease-dieback situation is temporary or permanent as far as its present severity is concerned adds to the confusion. We do know certain things, though:

- Failure to maintain/restore the environmental protection provided by the mangroves could have serious consequences.

- The Gambia's long-range wood supply outlook is sufficiently grim that the country cannot afford to ignore the wood production potential of the 63,000 hectares of mangrove swamp below the proposed barrage site.

- Mangrove forests elsewhere have been productive. For example, in Malaya average-site lands managed on a 34-year rotation have been estimated to produce 10 cubic meters of Rhizophora mangrove per hectare per year (4).

The message that comes through is that the mangrove forest will require some sort of management for environmental reasons alone. Beyond that, this forest can help meet future wood needs of The Gambia in the long run. Perhaps that contribution can be very substantial.

For this reason, the Department of Forestry should begin to make timber growth measurements and site classifications as soon as possible. It should also undertake such other studies as are necessary to provide an assessment of the growth potential of The Gambia's mangrove and the broad outlines of a future management program.

NOTES REGARDING SOURCE MATERIAL

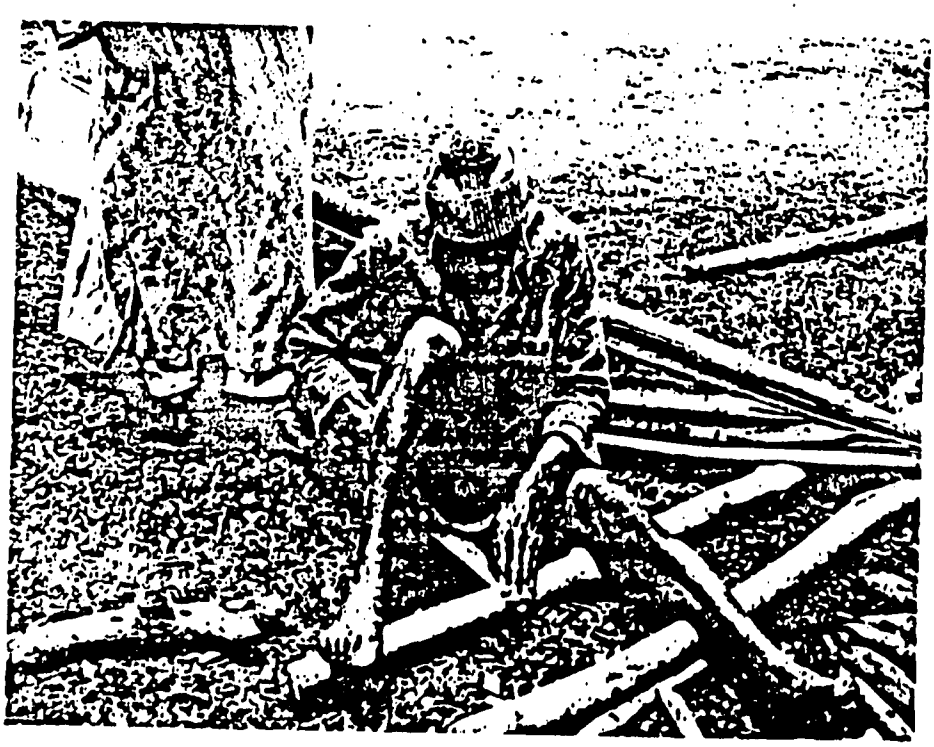
1. The CILSS/Club du Sahel, Forestry Sector Analysis and Programming Mission, Forest and Forestry in the Sahel, The Gambia--A Case Study, February 1981.

2. UNDP, Development of The Gambia River Basin, Final Mission Report, 1980.

3. Information from Dr. Marjorie G. Whiting, Lyon Arboretum, University of Hawaii, Honolulu, Hawaii.

4. Watson, J.G., 1928, Mangrove Forests of The Malaya Peninsula, Malayan Forester 6:1-275.

8. Mangroves are brought into Banjul.



9. Machetes sharpened with a few grains of sand are used for cutting green wood.

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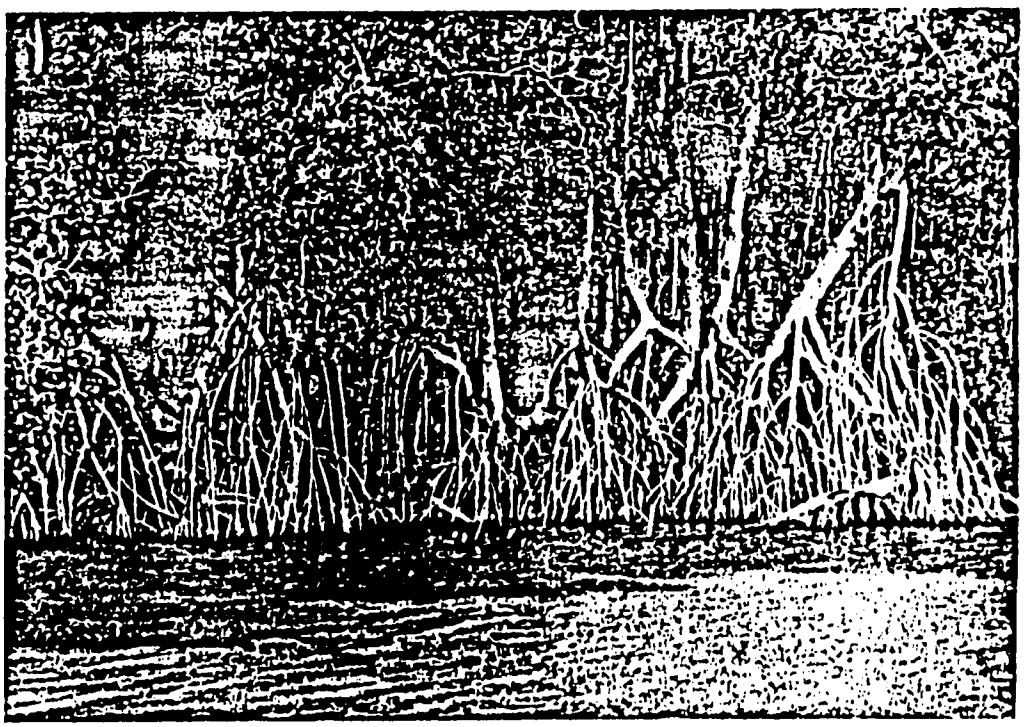
10. Some Rhizophora are very large--this one measured 104 cm in diameter.



11. Rhizophora prop roots can be dense and interlaced.

PART THREE - FINDINGS AND CONCLUSIONS

The conclusions and findings summarized briefly in the beginning of this report are repeated below in greater detail. Supporting information is in Part Two of this report.

- A major part of the Rhizophora mangrove protecting the shoreline of the Gambia River will be dead in five years.

  Approximately 75 percent of the Rhizophora timber is likely to be dead by 1986. This is the best part of the mangrove forest and includes many big trees. Avicennia mangrove growing behind the Rhizophora is not suffering unusual mortality, but this species does not fill the same ecological role in that it does not protect the stream edges, nor is it as suitable for industrial use.

- The immediate cause of Rhizophora mortality appears to be disease, but other factors may also be involved.

  Other environmental factors, such as drought, salinity, and acidity changes, and accelerated sedimentation may have created conditions of environmental stress that permitted the disease to run rampant. Further study of the causative factors is necessary.

- The salvaging of dead and dying mangroves could make a significant contribution to the Gambian economy.

  Not only could the mangroves provide much needed wood, a mangrove harvesting program would provide considerable local employment. The calculated sale price of mangrove suggests that retailers would be attracted to this operation. Training programs to teach appropriate logging methods should boost activity in existing training institutions. Sales of equipment and supplies, such as saws, machetes, files, petrol and oil would increase.

- The most desirable use for mangroves is fuelwood.

  Mangrove has certain limitations for industrial use. In addition, the resource supply is not large enough and The Gambia lacks the necessary infrastructure to support plants of the size required, in some cases. On the other hand, The Gambia is critically short of fuelwood and mangrove is an excellent energy source.

- Dead, dying, and harvested mangroves need to be replaced to protect stream banks and the adjacent environment.

The *Rhizophora* trees along the banks of the river and its bolons form a bulkhead that protects these banks from erosion. The loss of these trees would deal a serious blow to the functioning of the mangrove ecosystem and result in a great increase of siltation of the river bed. Below the barrage site, the *Rhizophora* mangrove stands need to be restored by a mangrove planting program. After the barrage is built and the reservoir becomes filled with fresh water, the mangrove stands will disappear because of cutting or competition. If they are largely replaced by reeds, the evapotranspiration probably will greatly increase over what it is now, thus increasing the water loss from evapotranspiration. Tree species that can thrive in non-saline conditions should be identified and planted.

- Mangrove management on a sustained-yield basis could provide a long-term source of wood for The Gambia.

The Gambia's potentially serious long-term wood shortage could be minimized by managing the mangrove forest for this purpose. This would take pressure off the upland areas, making it easier to develop forest management programs for The Gambia in general.

- Several institutions need to be involved in implementing a mangrove harvesting, processing, and marketing program.

If a serious effort is to be made to deal with the mangrove problem and capitalize on the opportunities available, the Department of Forestry needs to be strengthened to carry increased responsibilities. The Gambia River Transport Co. will be called upon, and some special organization will be required to manage and supervise the actual harvesting and marketing program.

- The Gambia has the capability to undertake this mangrove harvesting and marketing project.

Barges and trucks are available to handle the transport of fuelwood and there is a large pool of manpower seeking employment.

- A mangrove project as outlined can be environmentally beneficial.

The mass loss of *Rhizophora* mangrove is disrupting the local environment. If handled properly, harvesting, coupled with systematic planting, can actually help the ecological situation without impairing the wildlife habitat.

12. Our team found considerable amounts of dead and dying mangroves. At Darusalam on Bintang Bolon, Chief Toure said the trees had been dying for four to five years.

13. None of these trees appeared worth salvaging.

14. Borer holes on these Rhizophora show some considerable insect damage.

PART FOUR - RECOMMENDATIONS

The following recommendations are based on results of the study, its conclusions, and on suggestions made to us during the review of our draft report on August 21, 1981 in Banjul.

- The Gambia should initiate, as quickly as possible, a mangrove harvesting program principally directed to producing fuelwood.

  To delay harvesting the mangrove, or to do nothing at all, would result in the loss of a fuelwood resource in a country already on a crisis course insofar as energy is concerned. Areas to be harvested will have to be delineated by professional foresters or others trained by them. The Department of Forestry should take the lead in developing a management program and in supervising harvesting practices. Intensive training will be necessary at all levels. The Gambian-German forestry project should be requested to intensify its inventory of the mangrove forest to provide a better information base.

- The Department of Forestry should be directed to develop and initiate a tree planting program as soon as possible to replace dead, dying, and harvested Rhizophora mangroves

  Rhizophora species should be planted on all vulnerable areas below Elephant Island. Once the barrage is built and the water above the barrage point becomes fresh, mangroves will no longer be competitive and other tree species should be planted to replace them.

  Experimental plantings of mangroves from other parts of the world should be test planted to determine how well they thrive under local conditions. Pot culture experiments using washed mangrove soils (desalinized soils) should begin immediately to test the growth characteristics of "fresh water" tree species to replace the mangroves above the barrage for both bank stabilization and fuelwood.

  A stumpage fee, payable to the Department of Forestry, should be charged against the mangrove harvest to cover the expense of this research and development.

- Pilot-scale logging operations should be conducted before full-scale logging starts.

  Since mangrove logging on the scale proposed would be a completely new venture for The Gambia, a pilot test of the procedures, equipment, and crew organization is necessary.

- A quasi-public organization should be established to carry out and coordinate a mangrove harvesting and marketing program.

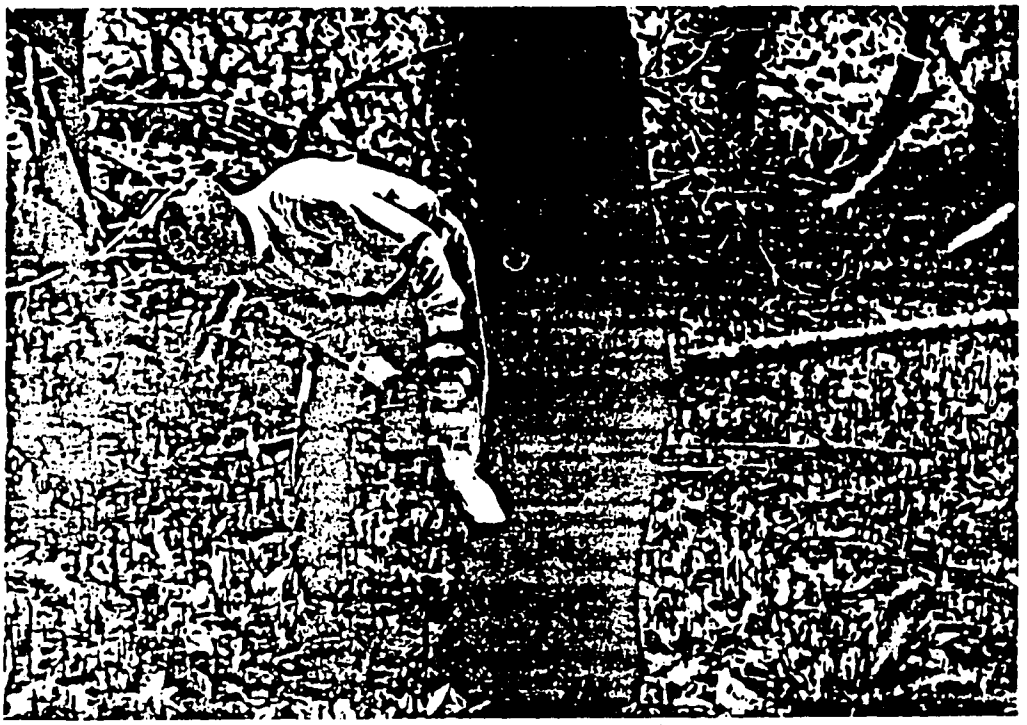
  Enabling legislation will be required to establish this organization which should be carefully structured to supervise and manage all facets of the operation from stump to market, in close coordination with the Department of Forestry. A system of financial accounting should be set up. Most of the actual production and marketing should be handled by contractors.

- The Rhizophora dieback disease should be monitored and studied in depth.

  Replanting of the river banks with Rhizophora mangrove in the presence of heavy mortality from the disease can be justified because, during their junior years, the trees are able to throw off the disease and provide bank stabilization. In the long run, however, this may not be the solution if the disease does not settle back to a tolerable level. A program, therefore, should be set up to study the dieback disease and monitor its progress so appropriate changes can be quickly made in management stragegy if the situation requires. As mentioned previously, a number of mangrove species from elsewhere in the world should be planted experimentally to see how well they do in this environment. This should provide a fall-back position if the disease continues to be virulent. Some of them may prove to be more vigorous and productive than the local mangroves.

- Information required to implement a mangrove management and harvesting program should be sought from other countries.

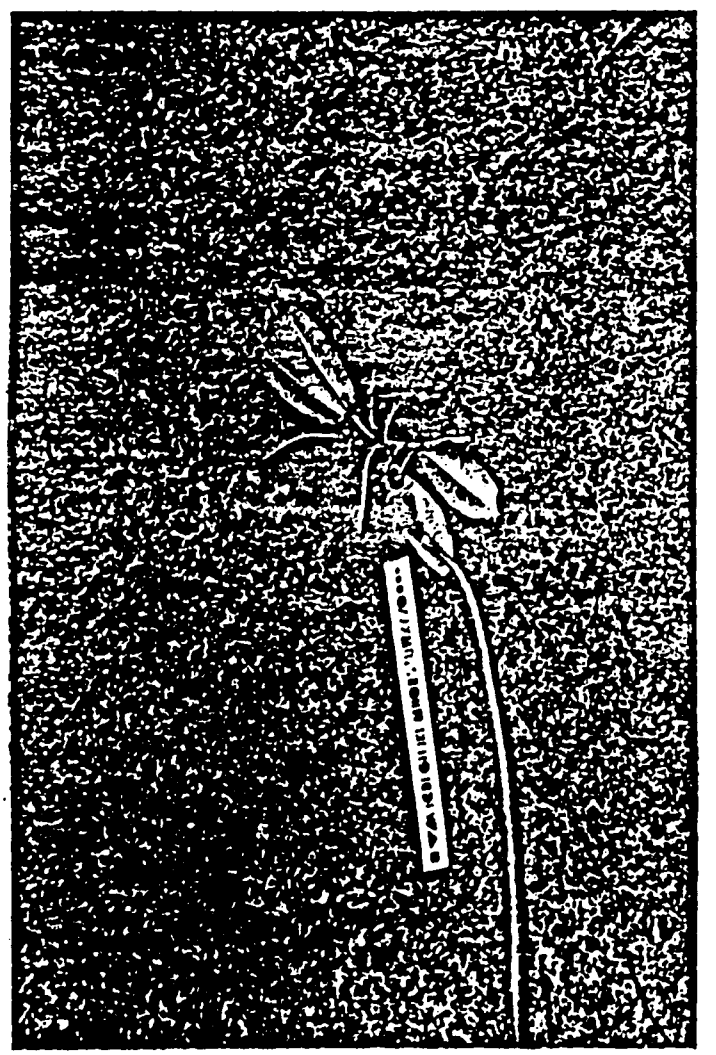
  The mangroves in The Gambia have received little management attention in the past. They have been managed and harvested elsewhere. An attempt should therefore be made to draw on this other experience to speed the process of developing a sound mangrove management program in The Gambia.



6. Some trees were cut to assess wood quality. This Avicennia, in contrast to Rhizophora, could be reached easily.

17. Natural succession may be sufficient to allow recovery after harvesting. Palms in the background and Rhizophora in the foreground is a typical situation upriver.

18. However, if Phragmites reeds take hold, Rhizophora may be crowded out.



19. Propagules (seedlings) should be planted after harvesting to restore

APPENDICES

Currency conversion rate
used in this report:
1 dalasi = $0.52 U.S.

Appendix One

Table A-1

MANGROVE TIMBER STANDS, 1978,

Stand Size Class 1/	Above Barrage Site hectares	Below Barrage Site hectares	Total Mangrove Forest hectares
Rhizophora 20+	3,605	2,520	6,125
Rhizophora 7-20	3,406	18,330	21,736
Avicennia 7+	708	8,310	9,018
Rhizophora 7-	594	11,880	34,464
Avicennia 7-		21,590	
Total	8,713	62,630	71,343

1/ Height in meters.

Data for above barrage site from Johnson, M.S., Inventory of Mangroves Above the Proposed Gambia River Barrage at Yelitenda, The Gambia, Project Report 54, Land Resources Development Centre, Surbiton, Surrey, England, 1978.

Data for below barrage site from Abell, T.M., Letter to R.J. McEwan, May 28, 1980, Overseas Development Administration, Land Resources Development Centre, Surbiton, Surrey, England.

Appendix Two

UTILIZATION OF MANGROVE

2-A Wood Characteristics of The Gambia's Mangrove

2-B Industrial Uses of Mangrove

2-C Non-Industrial Uses of Mangrove

2-D Imports-Exports-Balance of Visible Trade, The Gambia, Fiscal Years 1971-1981

2-E Oil Consumption and the Cost of Producing Electricity by the Gambia Utilities Corporation, Fiscal Year 1980

Appendix 2-A

WOOD CHARACTERISTICS OF THE GAMBIA'S MANGROVE

Although several different mangrove species grow in The Gambia, the two principal species are Rhizophora racemosa and Avicennia africana. The following information on their general properties is extracted from the publication, African Timbers--The Properties, Uses and Characteristics of 700 Species (12).

Characteristic	Rhizophora racemosa	Avicennia africana
Texture	Fine and even	Fine
Grain	Slightly crossed	Often interlocking
Workability	Planes fairly easily but some pick-up may occur with cross-grain material	Timber saws easily but is hard to work by hand
		Difficult to split in radial direction but not in tangential direction
	Nails and screws moderately well with good holding power	Takes nails and screws well but splitting may occur
	Takes a high polish; glues and paints satisfactorily	Stable
Seasoning	Tendency to split and warp	Difficult to season without twisting and checking
Durability	Good wearing and weathering properties	Moderate weathering properties
	Not susceptible to insect and fungus attacks	Highly durable in water and resistant to termites
Suitability for fuel	Makes excellent firewood and charcoal	Good fuel

Characteristic	Rhizophora racemosa	Avicennia africana
Weight at 12% moisture content		
Pounds per cubic foot	63-1/2 to 71	56-1/2 to 63
Kilograms per cubic meter	1,017 to 1,137	905 to 1,009

Table A-2 compares the properties of Rhizophora mangrove with selected other species, using four common measures:

- Modulus of rupture (MOR)
- Modulus of elasticity (MOE)
- Compression parallel to the grain
- Side hardness

The MOR, or bending strength, is a good measure of load bearing across the grain, such as when timber is used for a beam. The higher the psi value, the greater load the wood will sustain. The MOE value is a strength measure used to indicate stiffness or resistence to deformation in bending. The greater the psi value for MOE, the higher is the resistance of that species to failure due to loading in static bending. For measuring the strength of wood as a post or pole, compression parallel to the grain, or maximum crushing strength is a reliable indicator. In theory, those species of wood with greater compression values should make stronger posts and poles. Side hardness is a good measure of overall wood strength. All strength measures are directly related to specific gravity and moisture. Usually, higher density and lower moisture means higher strength values.

Table A-2

SOME BASIC WOOD PROPERTIES OF RHIZOPHORA MANGROVE AND OTHER SPECIES

Species	Moisture Content percent	Specific Gravity	Density lbs./cu.ft.	MOR p.s.i.	MOE Million p.s.i.	Compression Parallel p.s.i.	Side Hardness lbs.
Rhizophora mangrove	green 1/	.89	55.54	15,200	2.30	6,490	2,240
	air dry 2/	1.14	71.14	21,700	2.95	10,750	2,760
Lignum Vitae	air dry	1.09	68.02	-	-	11,400	4,500
African mahogany	air dry	-	-	10,700	1.39	6,460	830
White Oak	green	.60	37.44	8,300	1.25	3,560	1,060
	air dry	.68	42.43	15,200	1.78	7,440	1,360

1/ "green" condition in wood is any moisture condition above the fiber saturation point, usually about 30 percent moisture content.

2/ Air-dry condition in wood is most frequently 12 percent moisture content; tropical conditions (high relative humidity) will mean a higher equilibrium moisture content where dry air will be about 15 percent moisture content.

p.s.i. = pounds per square inch.

Source: Wood Handbook, Agriculture Handbook No. 72, 1974, Forest Products Laboratory, Madison, Wisconsin

Appendix 2-B

INDUSTRIAL USES OF MANGROVE

Pulp and Paper

In spite of relatively short fiber length, the use of hardwoods for pulp is constantly increasing as softwood supplies the world over have become increasingly unable to fill the need. Mangrove has been successfully used to produce pulp which in turn has been manufactured into paper or alpha cellulose (dissolving pulp) for rayon products.

Four factors are particularly relevant in considering the feasibility of a pulp and paper plant in The Gambia. Such plants are expensive and require large volumes of wood, water, and power. Pulp and paper mills cost about 768,000 dalasis per ton of annual output. A small plant by modern standards, would produce 100,000 tons each year and would cost about 77,000,000 dalasis to build. Unfortunately, there is not enough wood, water, or energy in The Gambia to support a pulp mill.

A 100,000-ton plant operating 350 days a year would consume about 617,000 cubic meters of wood annually, which is many times greater than all of the forests in the country could produce without seriously cutting into the supply of fuelwood for home consumption. In fact, at the present level of planting and management, the forests will not be able to continue to meet fuelwood needs alone. In general, pulp and paper plants require 40,000 gallons of water per ton of paper-producing capacity. Thus, a 100,000 ton plant would need four billion gallons of fresh water a year, an amount beyond the capacity of The Gambia to produce. No figures are available as to electrical energy requirements, but it is sufficient to say that they are very large and The Gambia's electrical production is very low (see discussion of particleboard).

Plywood and Veneer

Mangrove can be used to produce a good grade of high-density plywood and veneer suitable for paneling, cabinets, and furniture. Mangrove plywood panels would tend to be heavy, but that handicap would not apply to veneer which could be used as a face over lighter-weight woods.

It would cost about 6.7 million dalasis to build a small plywood-veneer plant producing 15,600 cubic meters of product annually (24 million square feet of 1/2 inch plywood and 20 million square feet of 1/20 inch veneer). The capital cost of such a plant is not excessive, but the electrical power requirements might be for The Gambia.

The Market for hardwood veneer and plywood in The Gambia is small but the international market for tropical woods has been steadily increasing. However, marketing a relatively untried species like mangrove could be difficult.

In this case, also, the limiting factor is wood supply. The small plant mentioned above would use 23,800 cubic meters of mangrove annually. This is not a great amount, but there is no assurance that the supply of Rhizophora mangrove would be sufficient to operate a plant for more than a few years because of the excessive mortality which is occurring. In any case a great deal of technical information would have to be gathered before veneer and plywood production from mangrove can be seriously considered.

Particleboard

Mangrove has not been used for commercial particleboard manufacture. However, it is possible to produce particleboard from many different kinds of wood.

There are four favorable factors as far as The Gambia is concerned:

- Although most of the particleboard production in the industrial countries is in large multimillion dollar plants, Bahre and Greten have designed small factories suitable for developing countries (11). The smallest would consume about 1,100 cubic meters of mangrove annually, well within the capacity of The Gambia to supply.

- Bahre's and Greten's particleboard plants are designed to be labor-intensive.

- Particleboard serves many purposes similar to plywood and can be produced from low quality wood unsuitable for plywood.

- The small plants mentioned above have the capability to produce particleboards that are smooth and of high quality.

There are, however, a number of unfavorable factors:

- Particleboard plants are heavy users of electricity. With less dense wood, the smallest plant designed by Bahre and Greten, even though labor-intensive, would require 972,000 kilowatt hours a year. A plant of that size using mangrove would require up to 1,500,000 kilowatt hours annually because of the high density of wood. The total electrical production by the Gambia Utilities Corporation in fiscal year 1980 was 22,101,000 kilowatt hours.

- Bahre's and Greten's cost analysis is based on 03.6 cents U.S. (.069 dalasis) per kilowatt hour. Because of rapidly increasing oil prices, electricity was costing 0.43 dalasis per kilowatt hour sold during fiscal year 1980. At that price, a particleboard plant which would be profitable at .069 dalasis

a kilowatt hour would lose 40 dalasis per cubic meter of particleboard produced, if all other costs and values were unchanged.

- The bone dry weight of southern pine, a species commonly used for particleboard in the U.S., is 642 kilograms per cubic meter. The bone dry weight of mangrove wood is 1,075 kilograms per cubic meter. A 4 foot by 8 foot sheet of mangrove particleboard would, therefore, be uncomfortably heavy to handle.

- Because mangrove is extremely hard, the cost of keeping the flaking knives sharp would be very high. As wood density increases, there is an almost linear increase in chipper knife wear. In other words, for a wood that is twice as heavy, the knives will have to be sharpened and replaced twice as often.

- There presently seems to be a worldwide excess of particleboard capacity over market demand for this product. Many particleboard plants in the United States have closed or are operating at very low production levels. Safety and environmental problems connected with particleboard manufacture further limit this as an alternative.

Electrical Energy

Wood has been long used in North America to generate electricity. Mostly it has been wood residue from lumber, plywood, and other timber processing plants. In the past few years, there has been renewed interest in wood generation of power because of the rapidly escalating price of fossil fuels. The opportunity exists in The Gambia, limited only by the availability of land to produce timber.

The energy value of mangrove is high. The following calculation is adapted from information obtained from A.B. Curtis, Wood Energy Specialist, United States Forest Service:

"As with all woods, mangrove has a Btu value of about 8,600 per oven dry pound (odp). Mangrove is a very dense species with a specific gravity of .89 (green). In the green condition, it has a moisture content (Mc) of about 40% (calculated on the dry basis). At a Btu value of 8,6000/odp and 40% Mc, the burning efficiency is calculated as follows:

$$\frac{}{1 + \frac{40}{100}} \quad .7143 \text{ lbs. wood/lb. of wood and water}$$

$$1 - .7143 \quad .2857 \text{ lbs. water/lb. of wood and water}$$

"Reineke (1947) states that the net useable heat from....green southern pine sapwood (assuming that this fuel contains equal weights of wood and water) is approximately as follows (ignoring humidity in combustion air):

Heat of combustion per lb. of dry wood	8,600 Btu
Less Heat loss associated with the evaporation of water content	1,210 Btu/lb. water
Less Heat loss associated with hydrogen combustion	660 Btu/lb. of wood and bark
Less Heat loss in other flue gases	690 Btu/lb. of wood and bark

"The same deductions may also be made for mangrove. Therefore, one pound of green mangrove at 40% Mc containing .7143 pounds of wood and .2857 pounds of water would have a burning efficiency as follows:

$$(8,600 \times .7143) - (1,210 \times .2857) - (660 \times .7143) - (690 \times .7143)$$

$$6143 - 346 - 471 - 493 = 4,833 \text{ Btu/lb. of green wood}$$

"This value should be further reduced 5% for other losses associated with humidity in combustion air, radiation, and other unaccounted for losses. This brings the net Btu value down to 4,591 Btu per green pound. The burning efficiency would be 75% (4,591 ÷ 6,143). This burning efficiency is probably the best that can be achieved. Further reductions would have to be made for less efficient machinery."

At the above net Btu value, 1 cubic meter of green mangrove chipped would be equivalent to about 62 gallons of number 6 furnace oil. Similarly, 1 cubic meter of green mangrove that has been air-dried, as in cordwood, would be equivalent to 66 gallons of number 6 oil.

The process of producing electricity alters the theoretical energy equivalents. The diesel generators operated by the Gambia Utilities Corporation are only 28 percent efficient in that the Btu's of energy coming off the generators are only 28 percent of the Btu's in the oil used to run the generating equipment. This is the normal situation. The greater part of the Btu's in green mangrove is lost in the process of producing electricity. How much depends on:

- The moisture content of the wood. The wetter the wood, the more energy is wasted drying it out.

- The efficiency of the steam boiler. A large amount of energy can be lost with a poorly designed or operated boiler.

- Typically, it takes 3 times as much energy to turn a generator as is produced in the form of electricity. About 10,000 Btu's of energy are required to generate 1 kilowatt hour which is equivalent to 3,413 Btu's.

Electrical production in The Gambia in fiscal year 1980 was 22,101,000 kilowatt hours. About 1.6 million gallons of diesel oil were used for generating the power. If a thermal plant were in operation, 33,900 cubic meters of green mangrove (40 percent moisture) would be required to produce that amount of electricity. If the mangrove were allowed to air dry before being hogged (chipped), only 20,000 cubic meters would be needed.*

How seriously electrical generation should be considered as an alternative use is a moot point. The Gambia's electrical consumption in 1980 was unusually small, about 37 kilowatt hours per capita per year. A few thousand hectares of fast-growing timber could provide the amount of wood needed for this amount of electricity. However, even if the consumption grows only moderately, there is some question whether there would be enough land left to produce timber for this use after the needs of agriculture and home fuelwood production have been met.

Activated Charcoal

One metric ton of regular charcoal can be produced from 3.7 cubic meters of mangrove. This is about a 26 percent yield by weight. In the United States, the price of this charcoal has ranged between $60 (115 dalasis) and $82 (157 dalasis) per metric ton. Activated charcoals sell for as much as 2,770 dalasis per ton. It will take additional study to determine if The Gambia can break into this high quality market.

A small--113 cubic meter per day--plant would require a capital investment of about 4,800,000 dalasis and the operating cost would be about 63 dalasis per metric ton of activated charcoal produced. Assuming a 19 percent efficiency for activated charcoal, 113 cubic meters of mangrove input per day would turn out 22 metric tons of charcoal. For a 300-day year, the output would be 6,600 tons plus 6,000 metric tons of creosote. Almost 34,000 cubic meters of wood will be required to support that annual output, an amount that seems too large to be considered at this time in view of the critical domestic need for wood.

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* This is a conservative calculation. Heavy energy losses were assumed. New equipment is being developed which should improve efficiencies.

Transmission Poles and Piling

Use of mangrove for poles and piling does have possibilities. Openshaw (10) in 1973 observed that, at that time, there was no use of mangrove for transmission poles, but "red mangrove (Rhizophora) seems ideally suited for such work."

A very small plant capable of producing about 100 poles and piles a week, working in a single shift--employing about 30 semi-skilled staff--could be established for a capital cost of about 480,000 dalasis, exclusive of land cost and cost of treating equipment. Operating expenses would be about 58,000 dalasis per year, exclusive of raw material costs and treatment costs. At 100 poles per week (average pole 40 feet long x 1 foot diameter), the total annual raw material required would be about 10,000 cubic meters.

However, since poles and piling, especially for export, have critical quality requirements, it will be necessary to carefully select the material that would be processed. For example, raw material for poles must be essentially defect free; free of rot, insect damage, reaction wood,1/ and large knots. In addition, the wood must have straight grain, and be free of compression failure, or other stress induced by felling.

Processing poles and piling involves debarking, shaving, framing, incising, and seasoning. Air seasoning from 3 to 6 months is essential if the poles or piling are to be treated. Vertical hot and cold dip treatment with creosote could be accomplished with a capital investment of about 960,000 dalasis, exclusive of land. Excluding raw material costs, operating expenses would be about 96,000 dalasis per year. This size plant would require a staff of 20 skilled persons. If pressure treatment is desired, a small, single-cylinder plant would require about 3,840,000 dalasis for capital investment, and about 154,000 dalasis per year operating cost.

Thus, costs for a small pole/piling plant could be estimated as follows: (100 pieces per week)

A. Untreated poles

1. capital costs = D480,000

2. production cost = D58,000 per year

1/ Reaction wood in hardwoods, known as tension wood, is abnormal (weak) wood formed on the upper side of a leaning stem, or in response to sustained wind stress.

3. a. staff - 30
   b. raw material - 200 cubic meters per week and 10,000 cubic meters per year

B. Additional costs for creosote treatment

1. hot and cold dip

   a. capital cost = D960,000
   b. production cost = D96,000 per year

      -staff 20
      -raw material, as above

2. pressure treatment

   a. capital cost = D3,840,000
   b. production cost = D154,000 per year

      -staff, as above
      -raw material, as above

To summarize, the capital investment and raw material requirements for a small pole plant are relatively modest. Production costs are medium. The question that has to be answered is whether there would be enough high quality Rhizophora mangrove available to supply the needs of a plant over a long enough period--particularly considering the high mortality rate of the Rhizophora. A special survey would be required to answer this question. A plant of the size described could produce many more poles and piles than could be used in The Gambia. It may be possible to develop an adequate outlet in neighboring countries. Until such time, the production of mangrove poles and piles would be a spasmodic activity.

Woodsugar/molasses (13, 14)

It is technically possible to produce wood/sugar molasses for livestock feed supplement from mangrove or any other timber. The Gambia needs supplemental feed for its cattle toward the end of the dry season.

The process of making wood/sugar molasses by acid hydrolysis has been known for a long time. However, only in Russia has there been large-scale production of animal feed supplements from wood. [illegible] molasses [illegible] be polluting waste materials.

Production of wood sugar molasses as a primary product has not been economically competitive in the Western world. Other producers of sugars from sugarcane, corn, citrus peelings, etc., do not have to

contend with the large lignin volume present in wood. Higher yields per unit of raw material are thus possible at lower cost. These other sources of sugars can flood the world market and the prices are often very low.

Even in a country short of foreign exchange to buy on world markets the opportunity seems limited. To avoid corrosion from the strong acids, materials more corrosion resistant and more expensive than stainless steel must be used for pipes and vats, making plant investment costs high--probably too high.

Two U.S. plants are producing a carbohydrate livestock feed supplement by cooking wood under high pressure for a few minutes. In both cases, however, aspen, a lightweight wood, is being used. Currently, it is not feasible to use a heavy wood like mangrove for this purpose.

Lumber, Furniture, Flooring, and Specialty Products

In 1973, Openshaw (10) estimated that almost 40 percent of the sawn wood used in The Gambia (about 2,096 cubic meters) was imported. There is therefore a market for more domestically produced sawn wood.

Mangrove has been used to manufacture lumber and *Rhizophora racemosa* seems reasonably suited for this purpose. However, as already mentioned, seasoning this wood is a serious problem, and uneven air drying often leads to significant warp, and hence, low quality lumber.

Effective seasoning of mangrove wood will probably require use of a small dry kiln. A small, compartment kiln with about a 12 cubic meter capacity would cost about 192,000 dalasis. A similar size solar kiln (not commercially available) would require about 58,000 dalasis to construct and fit out with instruments. Unfortunately, there are no kiln schedules (for either conventional or solar) now available for mangrove. Existing schedules for other high density tropical handwoods indicate that it would take two to three weeks to dry a charge of green mangrove to 15 percent moisture content. Drying costs would be about 41 dalasis per cubic meter in a conventional kiln, and about 12 dalasis in a solar kiln.

Furniture manufacture in The Gambia is both an industrial and non-industrial business, based on location (urban or rural), as well as raw material (wood or raffia bamboo). In 1972, Openshaw estimated that about 3,000 cubic meters of all materials (wood and raffia) were used in The Gambia to make furniture. Most commercial furniture is manufactured by a large number of small private shops, and in the GOTG, Banjul Public Works Department shop.

Rhizophora mangrove, correctly seasoned, could be worked into good quality furniture, and would probably take a good finish. At present, there is only a very small amount of solid information about working and finishing mangrove wood. Prior to developing any domestic or export furniture industry, it would be necessary to obtain more reliable information about working and finishing this wood.

Mangrove has been used on a limited basis for flooring. The high density of mangrove means that as flooring it will have a long service life. However, high density will make it somewhat hard to nail, so that adhesive would probably be used to fix flooring blocks to a sub-floor. The capital cost of a small plant to manufacture mangrove flooring blocks would be about 1,920,000 dalasis. However, prior to such a commercial venture, it would be necessary to know more about working, finishing, and gluing mangrove. In addition, a full market survey for mangrove flooring would be required.

Each year in The Gambia, a small volume of wood is used for crafts and special wood items. Wood carvers, working in very small one or two-man shops, are found throughout the country. These skilled craftsmen produce a variety of wood carvings with substantial value. Although Rhizophora mangrove is a high density wood, it seems to work fairly well, and some wood carvers indicate that they would use it, if available.

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Appendix 2-C

NON-INDUSTRIAL USES OF MANGROVES

Mangrove has been used to a limited extent for fence posts, roof rafters, and house parts. In 1973, Openshaw calculated that throughout The Gambia about 47 percent of the building material was sawn wood or poles. In the same year, Openshaw estimated that almost 20,000 cubic meters of wood was used for fence posts. Also, during this same period, he estimated that new buildings in The Gambia used about 25,000 cubic meters of wood, an average of 0.9 cubic meters per house.

Mangrove is already used, to a limited degree at least, for housing and fence posts in The Gambia. If only about 20 percent of the wood currently used for housing and fence posts could be replaced with mangrove, it would be a substantial market. If protected in housing use, or treated for use as fence posts, the high density mangrove should give a very satisfactory service life, and also make a high strength building member. Local foot bridges and other light structures may also be constructed with mangrove.

Based on the 1973 estimates of wood used in The Gambia for housing, substituting mangrove for 20 percent of that total would result in using about 5,000 cubic meters per year. On this same basis, use of mangrove for fence posts, at 20 percent substitution, would amount to about 4,000 cubic meters per year. In round figures, housing and fence posts could possibly use about 9,000 cubic meters of mangrove raw material each year.

Appendix 2-D

Table A-3

IMPORTS, EXPORTS, AND BALANCE OF VISIBLE TRADE, THE GAMBIA
Fiscal Years 1971 - 1981

Fiscal Year	Imports	Exports	Balance
	(thousand dalasis)		
1970/71	42,587	30,911	- 11,676
1971/72	46,216	35,491	- 10,725
1972/73	54,419	33,690	- 20,729
1973/74	63,495	67,607	+ 4,112
1974/75	88,349	84,833	- 3,516
1975/76	144,367	77,363	- 67,004
1976/77	169,834	109,246	- 60,588
1977/78	208,094	87,959	-120,135
1978/79	221,014	94,413	-126,601
1979/80	290,395	83,064	-207,331
1980/81			-255,000*

* Estimate based on first 8 months of fiscal year 1981.

Table A-4

EXTERNAL TRADE IN THE GAMBIA JULY 1980 - FEBRUARY 1981
COMPARED WITH THE SAME PERIOD IN SELECTED EARLIER YEARS

Period	Imports	Exports	Balance of Visible Trade
	(thousand dalasis)		
July 71 - Feb. 72	30,541	7,699	- 22,842
July 75 - Feb. 76	82,802	29,799	- 53,003
July 79 - Feb. 80	179,473	53,062	-126,411
July 80 - Feb. 81	180,957	25,193	-155,764

Source: External Trade Statistics of The Gambia, compiled by the Central Statistics Department, Ministry of Economic Planning and Industrial Development.

Appendix 2-E

TABLE A-5

OIL CONSUMPTION AND THE COST OF PRODUCING ELECTRICITY
BY THE GAMBIA UTILITIES CORPORATION
Fiscal Year 1980

Total electrical output	22,101,000 kilowatt hours
Total oil consumption	1,614,070 Imperial gallons
Electrical output per gallon of oil	13.69 kilowatt hours
Total cost of oil	3,303,465 dalasis
Average cost per imperial gallon during fiscal year	2.05 dalasis
Cost per gallon at end of year	2.77 dalasis
Average cost per kilowatt hour sold during year	0.43 dalasi

All of the electrical plants operated by the Gambia Utilities Corporation are powered by diesel engines.

Source: Gambia Utilities Corporation.

Appendix Three

HARVESTING SYSTEMS

3-A Productivity Levels and Unit Costs in Mangrove Harvesting

3-B Notes Regarding the Logging of Large Mangroves

Appendix 3-A

PRODUCTIVITY LEVELS AND UNIT COSTS IN MANGROVE HARVESTING

General Assumptions

- The logging calculations are based on a workday of 8 hours, a 5-day week, and 22-day month. This is conservative, but will make allowance for some non-productive time.

- In calculating production costs in the wood yard, a minimum wage of 5.4 dalasis per day for unskilled labor was used. Because working in the mangroves is difficult and unpleasant, a somewhat higher rate of 6.75 dalasis per day was allowed for unskilled woods labor.

- The rates for skilled labor in Table A-8 are proportionately higher for the same reasons.

- The cost of operating equipment (chain saws, boats, etc.) is based on experience elsewhere, adjusted to Gambian conditions.

- Although wage rates and productivity rates have been assumed in the following calculations, they are merely to establish cost expectations. All of the logging and other work in the mangrove swamp should be done under contract to assure cost control.

- Contract rates used in the analysis of barging and trucking have been based on stated rates, or deduced from an analysis of information collected.

Largewood Logging

The trees would be felled with saws and cut into 1/2 meter bolts. The bolts would be split into sizes easily carried and stacked along the riverbank or roadside. Three different types of work crew have been considered from the standpoint of composition, daily production, and costs. Small boat costs are included (Table A-6).

For the purpose of cost calculation, we have assumed the average largewood tree to be 48 centimeters in diameter and to have a wood volume of 1.6 cubic meters, including both stem and top-wood. The hand saw crew and the crew with one chain saw would produce eight cubic meters of fuelwood daily. The team with two chain saws would produce 15 cubic meters of wood each day.

The following tabulation shows the number of trees of each diameter class that would have to be cut to produce these volumes:

Centimeters	8 Cubic Meters Per Day	15 Cubic Meters Per Day
30	16 trees	31 trees
40	8	15
48	5	9
60	4½	8
70	2	3½

Because of their prop roots, Rhizophora mangroves must be cut above the prop roots. However, once each tree is felled, the prop roots and the portion of the trunk below the cut can be made into fuelwood. In a large tree, this can mean one or more additional cubic meters of wood.

Smallwood Logging

Smallwood stands which are extensive in area will be handled by conventional methods with machetes.

Although organized crews are not necessary and individuals could work independently, smallwood cutters should be organized into crews for convenience of supervision and transportation, with one person acting as supervisor and assuming responsibility for fulfillment of the contract. This is unskilled labor, and the base rate of 6.75 dalasis per day has been used in cost calculations.

Cutting crews of 16 would provide enough labor to produce reasonable daily production and lower unit costs of boat transportation. We have assumed a man-day output of 0.4 cubic meter.

Daily cost of each crew - 16 x D6.75 = 108 dalasis
Daily production per crew - 16 x 0.4m^3 = 6.4 cubic meters
Cost per cubic meter = 17 dalasis
Boat transportation for the crew would add 2.5 dalasis per cubic meter.

Barge Loading

Basis for loading cost calculations are:

120 pieces = 1 stere = 0.6 cubic meter
A bucket brigade system with crews organized into groups of 10 workers loading 24 pieces per minute.

Assuming 8-hour day (480 minutes) = 11,520 pcs. per day
Using an efficiency factor of .85 = 9,800 pcs. per day
= 49 cubic meters per day.

Table A-6

COMPARISON OF THREE LOGGING SYSTEMS
FOR LARGEWOOD MANGROVE STANDS 1/

Personnel	Daily Unit Cost Dalasis	Hand Saw Crew		Chain Saw Crew			
		Men	Dalasis	Men	Dalasis	Men	Dalasis
Fallers	9.5	2	19.0	1	9.5	2	19.0
Buckers	8.0	2	16.0	1	8.0		
Helpers	6.75	1	6.75			2	13.5
Splitters	6.75	2	13.5	2	13.5	3	20.25
Packers	6.75	5	33.75	5	33.75	10	67.5
Total Crew		12	89.0	9	64.75	17	120.25
Equipment		No.		No.		No.	
Chain Saws	20.0		-	1	20.0	2	40.0
Boats	15.0-19.0	1	15.0	1	15.0	1	19.0
Total Daily Cost			104.0		99.75		179.25
Daily Production - Cubic Meters			8		8		15
Unit Cost - Dalasis per Cubic Meter			13.0		12.5		12.0
Production per Man-day - Cubic Meters			0.67		0.9		0.9

1/ Approximately 15 percent of the volume will be in tree crowns and will be handled as smallwood.

However, it has been assumed that on the average 30% of the time would be wasted due to lack of barges, transportation time between barges, etc. Thus, the expected output per 10-man loading crew has been reduced to 34 cubic meters per day.

Foreman @ D9.0 x 1	=	9 dalasis
Loaders @ D6.0 x 9	=	54 dalasis
Total daily wages per crew		63
2 crews per barge		126
Crew boat (25 hp)		30
Total daily cost		156
Cubic meters loaded per day		68
Loading cost per cubic meter		2.3 dalasis

Loading costs are assumed to be the same for both smallwood and largewood. Productivity is considered to be conservative and if the work is done by contract, the estimated loading cost of 2.3 dalasis per cubic meter may be high.

Truck Loading

Special crews to load the trucks have been assumed for cost and employment calculations. However, harvesting crews could do the loading themselves with a similar unit cost.

Assume: 10 cubic meter truck loads (12 ton payload) and with 20% of total annual production being moved by truck directly to retail yards. Then 20,000 cubic meters per year at 225 days = 90 cubic meters per day.

9 truck loads per day, or 3 loads per crew

Crew:	head loader @ D9.0	=	9 dalasis per day
	5 loaders @ D6.0	=	30 dalasis per day
	Total		39 dalasis per day

Volume loaded per crew per day - 30 cubic meters
Average loading cost per cubic meter - 1.3 dalasis
To allow for lost time, this has been raised to 1.5 dalasis per cubic meter

Barge Transportation Costs

Barge transportation costs have been estimated on the assumption that the rate from Yelitenda to Denton bridge or some other point in that general vicinity would be 16 dalasis per ton. Since mangrove has a specific gravity of about 1.2, the rate per cubic meter in that case would be 19 dalasis.

Because the largewood is concentrated at or above Yelitenda, while smallwood areas are downstream, we have assumed the following average barge transportation costs per cubic meter:

Largewood - 20 dalasis
Smallwood - 17.5 dalasis

We have also assumed that 80% of annual fuelwood production would be transported by barge.

Truck Transportation

Truck haul calculations were based on a quoted rate of 200 dalasis to haul 12 cubic meters of upland wood 140 kilometers. This amounts to 17 dalasis per cubic meter. As mangrove is very heavy, we have assumed that the average truckload of this wood might be only 10 cubic meters. However, the average truck haul for mangrove would be considerably less than 140 kilometers. A typical truck haul might be 90 kilometers to Brikama. Therefore:

$$\frac{200 \text{ dalasis}}{10 \text{ cubic meters}} \times \frac{90 \text{ kilometers}}{140 \text{ kilometers}} = 12.9 \text{ dalasis per cubic meter}$$

Because trucking costs are not strictly proportionate to distance, the average truck hauling cost in this study was raised to 15 dalasis per cubic meter.

Barge Unloading and Stacking

For the purpose of calculating direct costs of unloading the barges and stacking the fuelwood in the depot, a two-shift operation was assumed. Following is the labor force and productivity per shift:

Unloading Crews - 4 crews of 8 men each plus 2 foremen and 1 supervisor.

Productivity per crew - 30 pcs. per minute or 14,400 pcs. per shift

Total per shift - 57,600 pcs.

at 120 pcs. per stere x .6 = 288 cubic meters
Reduced 22% = 225 cubic meters

Tractors and Carts - 2 drivers and 3 helpers operating 2 tractors each hauling 4 carts, carrying 2 steres (1.2 cubic meters) per cart.

Stacking Crews - 4 crews of 4 men each [illegible] the carts would be parked alongside the stacks. There would also be 2 foremen and 1 supervisor.

Costs	Number of Persons	Total Cost Dalasis
Unloading		
Supervisor @ D10	1	10
Foreman @ D6.5	2	13
Crew @ D5.4	32	173
	35	196
Tractor Hauling		
Operators @ D6.5	2	13
Helpers @ D5.4	3	16.2
	5	29.2
Stacking		
Supervisor @ D10	1	10
Foreman @ D6.5	2	13
Crew @ D5.4	16	86.4
	19	109.4
Total Labor		334.6
x 2 shifts		669.2

$$\frac{669 \text{ dalasis}}{450 \text{ cubic meters in 2 shifts}} = 1.49 \text{ dalasis per cubic meter}$$

rounded off to 1.5 dalasis

Truck Loading for Distribution to Retailers

To supply 80,000 cubic meters annually from the yard to retailers, about 25 truck loads of mangrove fuelwood (10 cubic meters per load) would have to be dispatched from the fuelwood depot each day--6 days a week. To move 250 cubic meters daily would require three 8-man loading crews and their supervisors.

	Number of Men	Total Daily Cost Dalasis
Loading Supervisor @ D10	1	10
Foreman @ D6.5	3	19.5
Crew @ D5.4	24	129.6
		159.1

The loading of trucks, therefore, costs 0.6 dalasi per cubic meter.

Wood Depot Management and Operation

		Number of Men	Total Annual Cost Dalasis
Staff:	Manager @ D15,000	1	15,000
	Shift Supt. @ D6,500	2	13,000
	Mechanics @ D5,000	2	10,000
	Tallymen @ D2,000	4	8,000
	Accountant @ D7,000	1	7,000
	Office Staff @ D4,000	2	8,000
Staff salary, total annual allowance			61,000
Tractors: depreciation & operating costs			50,000
Employee transportation			50,000
Miscellaneous			30,000
Total wood yard operations (exclusive of direct labor)			191,000

@ 80,000 cubic meters per year - 2.4 dalasis per cubic meter

Summary of Direct Operating Costs

	Barge Transport 80%		Truck Transport 20%	
	Largewood 70%	Smallwood 30%	Largewood 70%	Smallwood 30%
	dalasis per cubic meter			
Falling, bucking, stacking	12.0	19.5	10.0	17.0
Transport to roadside	-	-	5.0	5.0
Barge or truck loading	2.3	2.3	1.5	1.5
Transportation	20.0	17.5	15.0	15.0
Unloading barges and stacking wood	1.5	1.5	-	-
Other storage yard costs	2.4	2.4	-	-
Truck loading and transport to retail yard	5.0	5.0	-	-
Total direct operating costs from stump to retail yard	43.2	48.2	31.5	38.5

Weighted Average Direct Operating Costs delivered to retail yard = [illegible]

Capital Expenditures

The chain saws required for the logging operation described will cost about 1,500 dalasis each, including the spare parts needed.

	Dalasis
Chain saws	1,100
Spare bars	200
Extra chains, etc.	200
	1,500

Forty-five crews would need 90 saws. The initial purchase should include at least 130 chain saws. Including other tools and equipment, the total initial investment should be about 220,000 dalasis. The amortization of this amount is included in the operating cost.

These calculations include 90 boats and motors for moving crews. It was impossible to get a firm idea what the boats might cost, but the total capital investment in these items should be about 400,000 dalasis.

Boats and Motors	Horsepower	Unit Cost - Dalasis Motor	Boat	Total	Total Cost Dalasis
40	7.5	1,700	1,800	3,500	140,000
30	9.9	2,000	2,500	4,500	135,000
10	15.0	2,400	2,700	5,100	51,000
5	25.0	2,700	3,300	6,000	30,000
5	35.0	2,900	4,100	7,000	35,000
					391,000

The fuelwood depot would require a capital expenditure of about 450,000 dalasis.

	Dalasis
Surfacing (2 hectares)	200,000
Facilities (dock, office, lighting)	200,000
Miscellaneous (small tractors, carts, etc.)	50,000
	450,000

Equipment Operating Costs

It has been assumed from North American logging experience that chain saws would be worn out at the rate of about 1.5 saws per year. The Operating costs therefore are:

	Dalasis
Depreciation 1,500 dalasis x 1.5	2,250
Repairs at 33% of capital cost	750
Fuel and oil	1,500
Annual cost of operating one chain saw	4,500
Daily cost including 20% margin	20

It has been assumed that outboard motors and boats will be worn out in two and five years respectively.

	Size of Motor - Horsepower				
	7.5	9.9	15	25	35
	dalasis				
Motor depreciation (2 yrs)	850	1,000	1,200	1,350	1,450
Repairs	425	500	600	675	725
Fuel and oil	1,500	2,000	2,500	3,500	4,500
Boat depreciation (5 yrs)	350	500	550	650	800
Boat repairs	200	250	300	350	400
Total annual cost per unit	3,325	4,250	5,150	6,525	7,875
Daily cost per unit including 20% margin	15	19	23	30	36

POSSIBLE FLUCTUATIONS IN EMPLOYMENT
WHEN THE MANGROVE HARVESTING IS IN FULL OPERATION

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
LOGGING OPERATION												
Saw crews												
number of crews	(45)	(45)	(45)	(45)	(45)	(40)	(10)	(10)	(10)	(30)	(45)	(45)
persons	540	540	540	540	540	480	120	120	120	360	540	540
Smallwood loggers												
persons	400	400	400	400	400	200	-	-	-	200	400	400
Barge loaders												
persons	90	45	45	45	90	130	90	90	90	120	130	130
Truck loaders												
persons	18	18	18	18	18	18	18	18	18	18	18	18
Total woods												
persons	1,048	1,003	1,003	1,003	1,048	828	228	228	228	698	1,088	1,088
FUELWOOD DEPOT												
Barge unloaders & stackers												
persons 1/	80	40	40	40	80	120	80	80	80	120	120	120
Truck loaders												
persons	28	28	28	28	28	28	28	28	28	28	28	28
Woodyard staff												
persons	12	12	12	12	12	12	12	12	12	12	12	12
Total depot												
persons	120	80	80	80	120	160	120	120	120	160	160	160
Total Employment												
persons	1,168	1,083	1,083	1,083	1,168	988	348	348	348	858	1,248	1,248

1/ Two shift basis most of year.

Note: These figures do not include the truckers that move fuelwood from the forest areas to the Brickama-area retail yards. The average will be six truck loads a day. Nor do they include the truckers moving wood from the depot to the retail yards in the Banjul, Sere Kunda, and Bakau areas.

Table A-8

POSSIBLE FLUCTUATIONS IN WOOD PRODUCTION, TRANSPORTATION, SALES, AND INVENTORY WHEN THE MANGROVE HARVESTING SYSTEM IS IN FULL OPERATION

(thousand cubic meters)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
HARVESTING													
Largewood area	8.0	8.0	8.0	8.0	8.0	7.0	1.5	1.5	1.5	5.3	8.0	8.0	72.8
Smallwood area	3.4	3.4	3.4	3.4	3.4	1.7	-	-	-	1.7	3.4	3.4	27.2
Total	11.4	11.4	11.4	11.4	11.4	8.7	1.5	1.5	1.5	7.0	11.4	11.4	100.0
TRANSPORT													
Barge	6.5	3.3	3.3	3.3	6.4	9.5	6.4	6.4	6.4	9.0	9.7	9.7	79.9
Truck	1.7	1.7	1.6	1.7	1.7	1.6	1.7	1.7	1.6	1.7	1.7	1.7	20.1
Total	8.2	5.0	4.9	5.0	8.1	11.1	8.1	8.1	8.0	10.7	11.4	11.4	100.0
SALES													
Depot	6.7	6.7	6.6	6.7	6.7	6.6	6.7	6.7	6.6	6.7	6.6	6.6	79.9
Truck	1.7	1.7	1.6	1.7	1.7	1.6	1.7	1.7	1.6	1.7	1.7	1.7	20.1
Total	8.4	8.4	8.2	8.4	8.4	8.2	8.4	8.4	8.2	8.4	8.3	8.3	100.0
INVENTORY ACCUMULATION FOR YEAR													
In Forest	3.2	9.6	16.1	22.5	25.8	23.4	16.8	10.2	3.7	0	0	0	
In Depot	-0.2	-3.6	-6.9	-10.3	-10.6	-7.7	-8.0	-8.3	-8.5	-6.2	-3.1	0	
Total	3.0	6.0	9.2	12.2	15.2	15.7	8.8	1.9	-4.8	-6.2	-3.1	0	

1/ Does not include two months supply (about 17,000 cubic meters) which would be accumulated before sales begin from the wood depot.

Appendix 3-B

NOTES REGARDING THE LOGGING OF LARGE MANGROVES

When logging large timber, the trees must be felled systematically with full control of the direction of fall. In general, this means falling each tree into an opening so that it will not hang up on other trees.

Hand cross cut saws must be considerably longer than the diameter of the trees to be logged. They should not be any shorter than 150 centimeters; 180 centimeters may be better. The bar on a chain saw should be somewhat longer than one-half the diameter of the larger trees to be cut. Generally, 60 centimeter or 75 centimeter bars will be satisfactory.

Although a chain saw is operated by one man and a hand saw by two, the felling techniques are the same. The FAO training series handbook, Chainsaws in Tropical Forests (FAO Training Series #2), is an excellent manual to follow.

The Basic Technique of Falling Timber

Figure A-1 shows where the saw cuts should be made for directional falling. On straight trees, the undercut should enter about one-third of the diameter of the tree. The wedge-shaped piece must be completely removed. The back-cut should be made opposite and above the undercut, care being taken to leave some holding wood, as shown. Vertical trees with but a slight lean can be felled in any direction, particularly with use of wedges.

Trees with a greater lean or trees with a heavy crown on one side must be felled in the general direction of the lean. However, they can be directed within a more or less limited arc. Figure A-2 shows that a tree with a modest lean can be controlled over a fairly wide arc by leaving extra holding wood and using a wedge. Trees with a heavy lean can be controlled only slightly by deviating from normal practice by making the inner side of the back-cut first, as shown in Figure A-3.

Techniques Specific to Rhizophora Trees

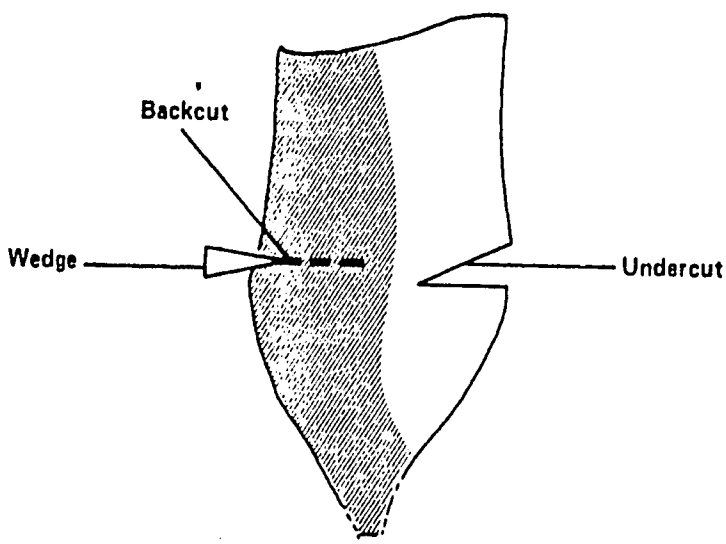
The prop roots of Rhizophora trees make it very difficult for a faller to cut just above the prop roots, where he should.

Two techniques are available to overcome this difficulty:

- Build a simple platform to allow the faller to stand at the desired height and location to make the cuts. This is described and illustrated in the FAO Chainsaw Handbook.

Figure A-

ELEMENTS OF DIRECTIONAL FALLING



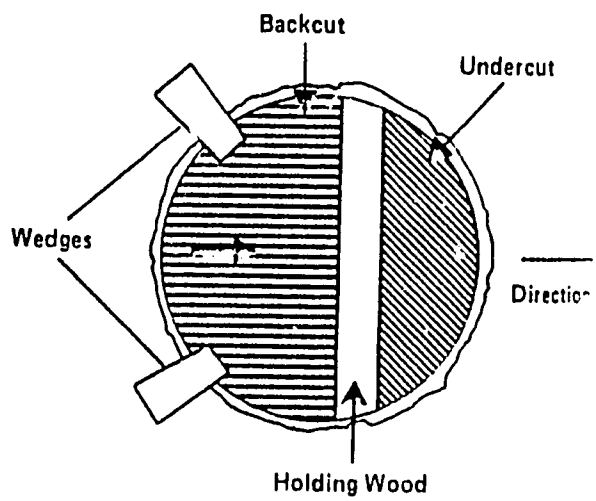


Figure A-2

TREES WITH MODERATE LEAN

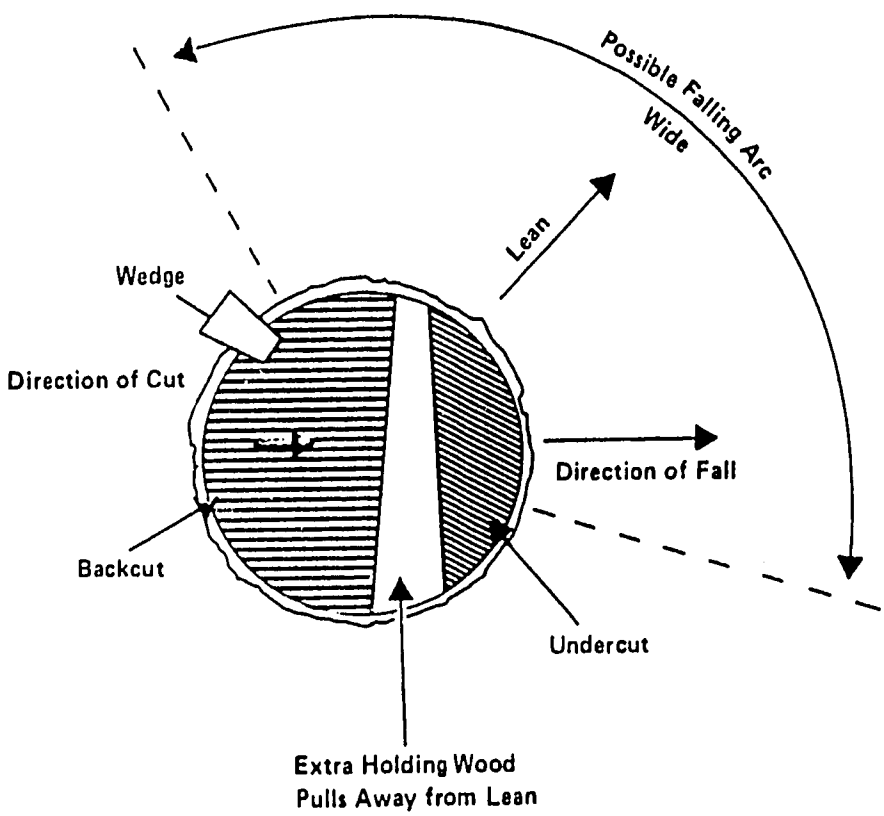
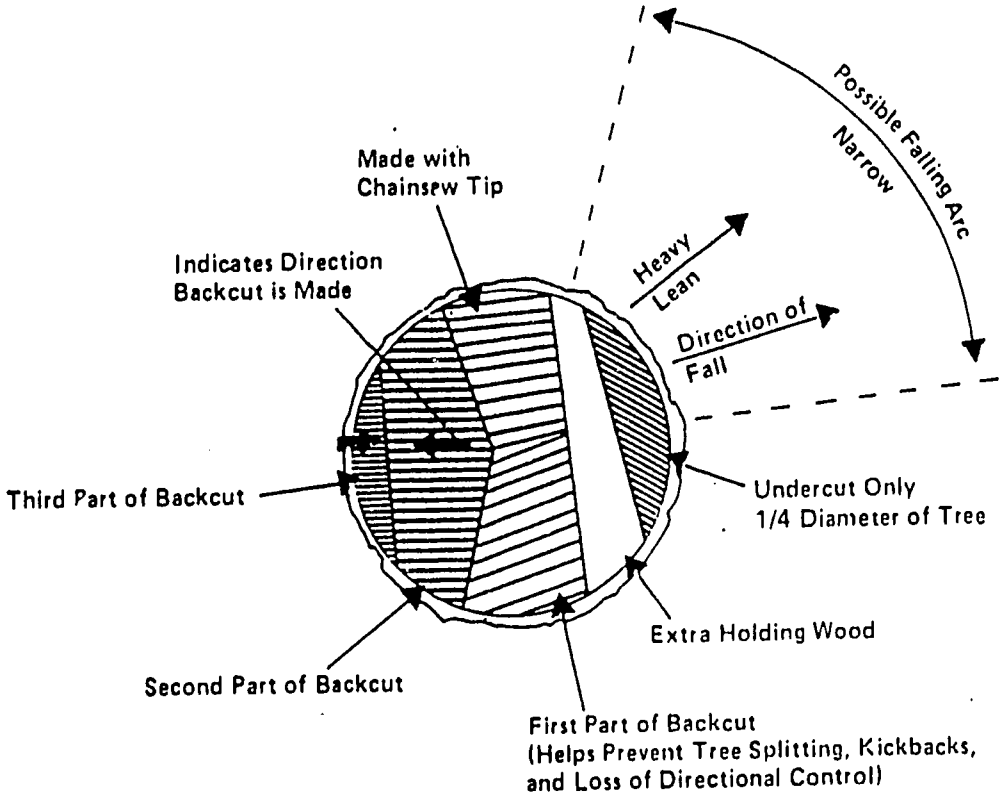


Figure A-3

TREES WITH HEAVY LEAN



- Use "springboards" which fit into notches cut into the side of the tree. This is a more rapid and simpler method than building a platform.

A springboard can be shaped to suit the faller's preference and can be of any length. Figure A-4 shows a typical springboard. The lighter the springboard is, the better because the faller or his helper must carry it; but it must be strong enough. The board is replaceable. A non-slip surface makes it much easier to maintain one's position while operating the saw.

The board shown has a metal tip that is bolted to the board or platform. The metal end is fitted into a notch in the tree, which if cut correctly, holds the springboard firmly. See Figure A-5.

Chain Saw Care

The salt air and salt water in mangrove swamps corrodes most tools rapidly. To reduce corrosion, special preventive maintenance procedures will be required, in addition to the normal ones.

- The chain bar and the chain should be washed off with fresh water at the end of each working day. Lubricate after washing.

- Weekly, the bar and chain should be removed from the power head and washed thoroughly in fresh water. The chain should be soaked in oil overnight. The power head should be wiped clean with fresh water and all exposed parts lubricated thoroughly. Water must not be allowed to get inside the power head.

- On the work site and while traveling back and forth by boat, the chain saw should be protected as much as possible from exposure to the saltwater environment.

Figure A-4

SPRINGBOARD

Metal Tip · One Design

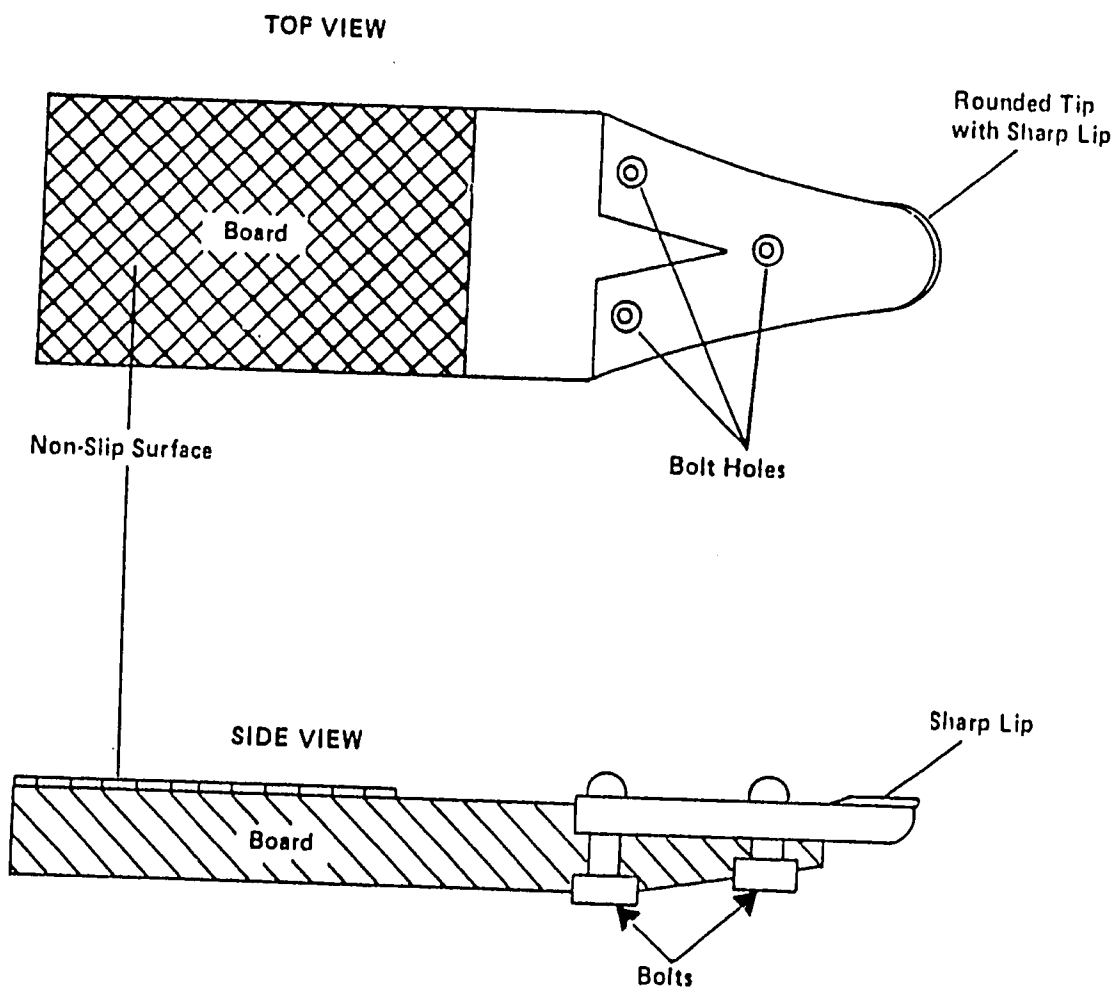
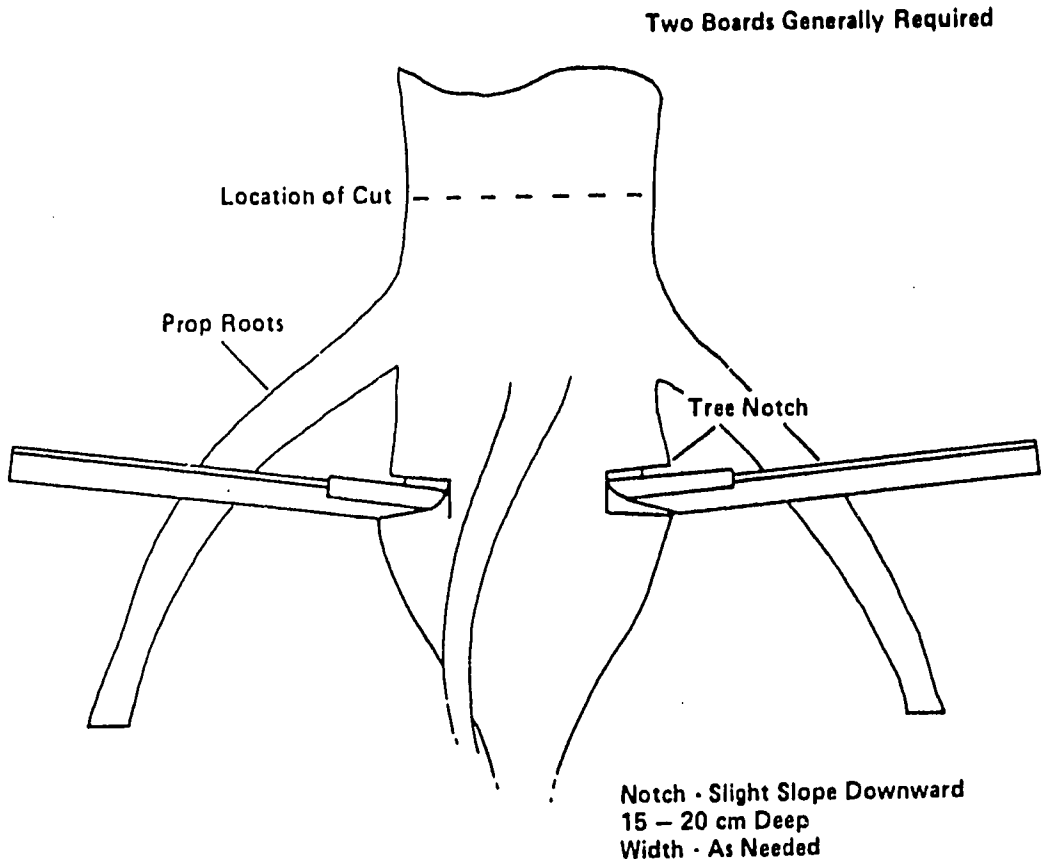
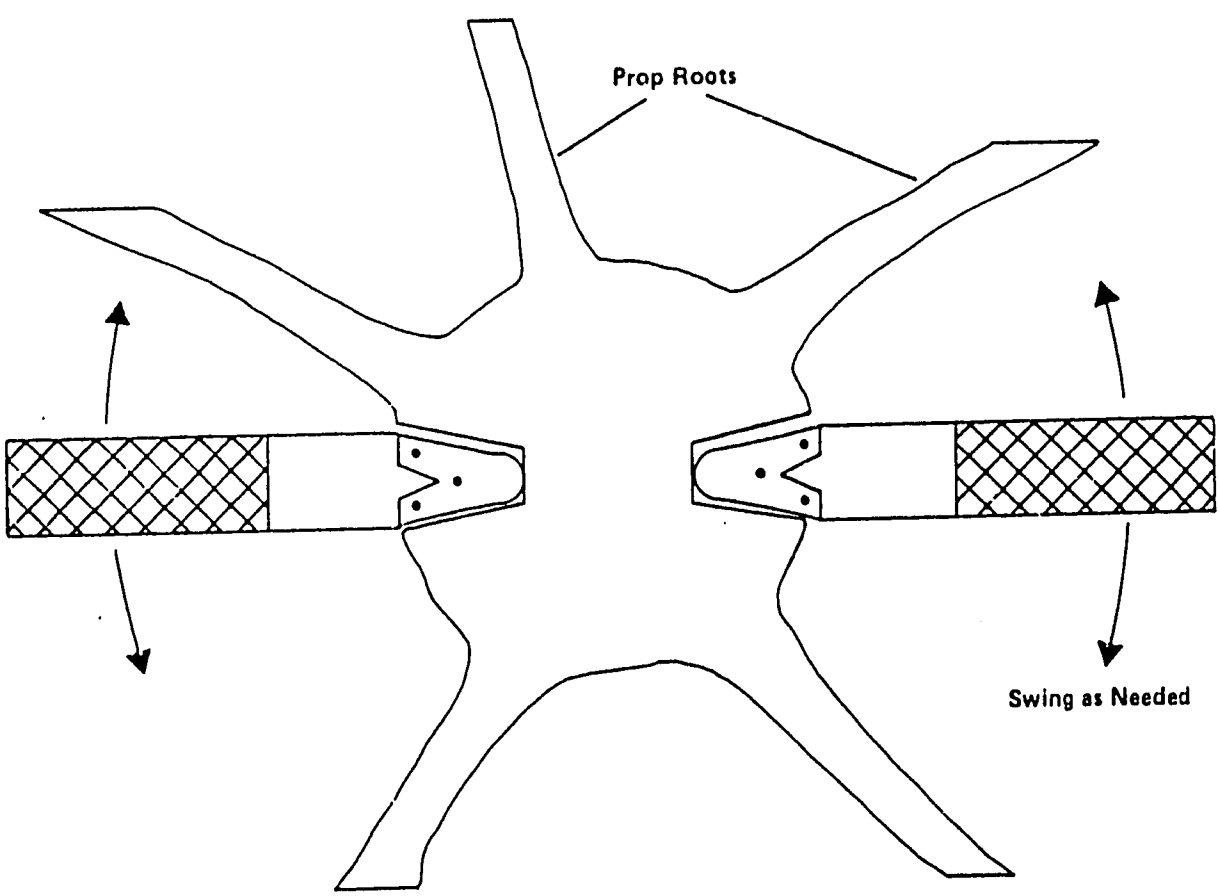


Figure A-5

SPRINGBOARD INSTALLATION





Appendix Four

INSTITUTIONAL INFRASTRUCTURE AND MANPOWER MOBILIZATION

4-A Freight Rates Charged by the Gambia River Transport Company

4-B Lighter Fleet of the Gambia River Transport Company

4-C Tug Fleet of the Gambia River Transport Company

4-D Current Income Rates in The Gambia

Appendix 4-A

FREIGHT RATES CHARGED BY THE GAMBIA RIVER TRANSPORT COMPANY

Table A-9

RATES FOR CARRYING FARM PRODUCE BY
GAMBIA RIVER TRANSPORT COMPANY LIGHTERS

(A)	(B) Cost In Dalasi Per Ton	(C) Costs Per Ton/Mile	(D) Basis for Calculation of (C)
Zone I, 1-25 miles	15.18	D1.17	(15.18/13 miles)
Zone II, 25-49 miles	18.12	.49	(18.12/37 miles)
Zone III, 50-89 miles	24.24	.35	(24.24/69.5 miles)
Zone IV, 90-129 miles	27.30	.25	(27.30/109.5 miles)
Zone V, Over 130 miles	30.25	.14	(30.25/215 miles)

Table A-10

FREIGHT CHARGES FOR GENERAL CARGO (RICE, FERTILIZER, ETC.)
GAMBIA RIVER TRANSPORT COMPANY

Banjul to Kemoto	D15.39
Bankul to Kerewan	15.39
Banjul to Sankwia	15.39
Banjul to Kau-ur	15.39
Banjul to Kuntaur	15.90
Banjul to Georgetown	18.48
Banjul to Bansang	19.80
Banjul to Diabugu	22.50
Banjul to Basse	24.00
Banjul to Fatta Tenda/Fatoto	26.50

Source: Gambia River Transport Company; columns (C) and (D) derived by Checchi and Company in consultation with Gambia River Transport Company. The rates in Table A would be applicable to cut mangrove wood.

Appendix 4-B

LIGHTER FLEET OF THE GAMBIA RIVER TRANSPORT COMPANY
As of June 1981

Lighter No. or Name	Capacity (MT)
BH 1	140
BH 2	140
BH 3	60
BH 4	140
BH 5	140
BH 6	140
BH 7	140
BH 8	60
BH 9	140
BH 10	60
BH 11	140
BH 12	140
BH 13	140
BH 14	140
BH 22	90
BH 23	90
BH 24	110
BH 25	110
BH 26	110
BH 27	110
BH 28	60
BH 29	80
BH 30	80
BH 31	60
BH 33	20
BH 38	20
BH 40	20
BH 41	90
BH 42	90
BH 43	60
BH 44	60
BH 45	60
BH 47	70
BH 49	50
BH 52	100
BH 53	100
BH 54	100
BH 55	200
BH 57	200
BH 58	100
BH 59	100
BH 60	150
BH 61	150
BH 62	150
BH 63	150
BH 64	150
BH 65	150
BH 66	100
BH 67	100
BH 68	100
Benares	130
Raglan	130
Invercargill	130
Erol	130
Nobby	35
Macina	70
BH 56	200
Total Capacity	6,085
Total number of lighters	57
Average capacity per lighter	107

Appendix 4-C

TUG FLEET OF THE GAMBIA RIVER TRANSPORT COMPANY
As of June 1981

Name	Engine or Description
M/T. Kuntadur	Paxman, RPM 6500
M/T. Kaba II	Paxman, RPM 6500
M/T. Wasp	Pasman, RPM 6500
M/T. Ambeni	Caterpillar, D333
M/T. Sandu	Caterpillar, D300
M/T. Suncannon	Caterpillar, D333
M/T. Pelican	Caterpillar, D300
M/V. Macina	n.a.
M/T. Ayube	Kelvin,. 130 UR

Note: M/T = Motor Tug

Appendix 4-D

CURRENT INCOME RATES IN THE GAMBIA

Unskilled wages currently quoted in The Gambia range from 3.50 dalasis per day for farm work up to 5.65 dalasis. The lower rate of 3.50 dalasis per day for farm-related work is below the established minimum rate.

Income from self-employment generally is higher. Information from woodcutters indicate that the organizers can earn around 10 dalasis a day. Their helpers, who are usually paid by the quantity of wood they cut, apparently each net about half that amount.

Fishermen from Jarreng who own boats indicate that this year they individually netted between 15 and 25 dalasis per day, depending upon their equipment, skill, and time invested. Those helping the boat owners earned approximately 10 dalasis per day.

Appendix Five

ENVIRONMENTAL ASPECTS OF MANGROVE UTILIZATION

5-A Mangrove Resources and Ecosystem Relationships

5-B Procedures and Cost of Planting Mangrove Sites Along the Gambia River and its Bolons

5-C Mangrove Soils

Appendix 5-A

MANGROVE RESOURCES AND ECOSYSTEM RELATIONSHIPS

General. Mangroves are the trees and shrubs that grow at the edge of the sea in many tropical and subtropical regions of the world. Mangroves thus defined by their ecology are a taxonomically diverse group that includes at least 12 plant families and more than 50 species.

Mangrove species do not appear to be obligate halophytes. They compete successfully in the saline tidal areas but in non-saline waters or where they become seeded upland, they are poor competitors, probably because they grow slowly and are shaded out by faster growing freshwater hydrophyte or upland species (Teas, 38). Nevertheless, some mangrove genera, such as Avicennia, are rarely found growing in waters of low salinity and others, such as Rhizophora mangle, grow better in salty or brackish water than in fresh water (Teas, 39).

Silviculture. Silviculture of mangroves was practiced in the Andaman Islands before the beginning of this century and in Malaya since 1904 (Watson, 44). Noakes (22) estimated that 82 percent of the 145,000 hectares of mangrove forest in Malaya was under sustained yield management in Forest Reserves. Mangrove forests also have been managed in Thailand, the Philippines, and parts of Vietnam (Teas, 39).

The Rhizophora have large propagules (seedlings) that are ideal for establishing themselves beneath the parent tree. However, the propagules are poorly suited for water dispersal within the forest, and may be completely prevented from reaching a felled area by accumulations of slash which, according to Macnae (19), requires three years to decay. Watson (44) reported that even wet areas (subject to frequent tidal inundation) could not be relied upon to regenerate naturally.

Clear-cut mangrove forests may fail to regenerate because slash excludes seed supply, but other factors can be involved. Holdridge (13) noted in Puerto Rico that in some clear-cut mangrove areas there was no natural regeneration and that, furthermore, he had little or no success in establishing hand-planted seedlings. He found that such areas were hypersaline salitrals. Macnae (19) reported that areas where mangroves had been clear-cut often became deserts, useful only for salt production. He cited examples along the Gulf of Thailand, east and west of Bangkok. Local vegetation-free areas called salt pans are known to occur in salt marshes where past piled-up decaying vegetation killed the plants locally and conditions became unfavorable for their re-establishment (Chapman, 5; Pethick, 26). Under some conditions, high temperatures and increased evaporation in clear-cut mangrove areas can raise the soil salinity so that mangroves are unable to become re-established.

A factor other than salinity that may be involved in the inhibition of mangrove regrowth in clear-cut forest areas is the chemical changes that can occur in exposed soils. Baltzer and Lafond (1) reported that bare hyper-saline areas in salt marshes were frequent sites of acid sulfate soils, i.e., cat-clays which, upon drying, can become too acidic for plant growth.

Uses. Mangroves are managed because they are an important source of a variety of wood products. Reported uses of mangroves include: timber, railroad sleepers, boat ribs and planks, furniture, scaffolding, dock-pilings, tool handles, poles for fish traps, fence posts, posts for house construction, matchsticks, packing boxes, and pencils. The wood of several mangrove species (e.g., Rhizophora species) is highly valued as firewood because it splits readily, burns evenly with little smoke, and yields high caloric value charcoal. The wood of mangroves that produce smoke is used for smoking sheet rubber and fish and, less often, used as fuel (Watson, 44).

The leaves of Rhizophora were found to be suitable as cattle food in Florida and Avicennia leaves are regularly fed to water buffalo and cattle in India and to camels in East Africa. Mangroves have been used for medicinal preparation, such as poultices, treatment for diarrhea, diabetes, and an array of other conditions (Bhosale, 2; Morton, 21).

Biological Value. Mangroves are important biologically as producers of food materials and as habitat for a variety of organisms. Mangroves are a source of energy for estuaries and shoreline communities. They produce leaves, twigs, fruit, flowers, and wood that contribute to the detrital food chain of the swamp. The details of such a food chain were worked out by Odum and Heald for a Florida Rhizophora forest (23). Such a food chain is likely a general one for mangrove swamps. Utawale, et al, have reported evidence for a parallel detrital food chain in an Indian mangrove estuary (43).

Mangrove swamps support a diverse fauna that includes crabs, prawns, molluscs, and other invertetrates, as well as fish, birds, amphibians, reptiles, and mammals. Many commercially important fish use mangrove waterways in at least a part of their life cycle. In Florida, the mangrove habitat has been identified as a nursery and feeding ground for such commercially valuable marine species as the pink shrimp (Panaeus duorarum), mullet (Mugil cephalus), gray snapper (Lutjianus griseus), red drum (Sciaenops ocellata), sea trout (Cynoscion nubulosus), and blue crab (Callinectes sapidus) (Odum and Heald, 23). Some of these or related species utilized in The Gambia (for example, penaeid shrimp, mullet, and blue crab) are mangrove dependent.

Macnae (20) studied the correlation of prawn (shrimp) catches with mangrove forests and summarized mangrove area and prawn fishing yield for portions of the Indo-Pacific in which he had catch records, i.e.,

Mozambique, Madagascar, West Thailand, Malaya, and the combined Irian, Papua and north Australia. He found that mangrove area and prawn harvest in the vicinity were generally correlated, as were mangrove area and finfish catches.

Shoreline Protection. Mangroves have been widely recognized as playing an important role in the protection of shorelines from erosion and storms. Rhizophora mangle was introduced into Hawaii in 1902, where it was planted on the lee shore of the island of Molokai to control erosion (MacCaughey, 18). Today, the mangrove forests in that area are extensive. On the counter side, Fosberg (9) has suggested that past removal of thousands of hectares of mangroves in Bangladesh may have been partly responsible for the heavy loss of life in the 1970 storm and tidal wave.

Species in The Gambia. The mangroves of The Gambia consist of species of Rhizophora, the red mangrove or mankwo; Avicennia africana P. Beauv, the black mangrove or jumbukungo; Laguncularia racemosa (L.) Gaertn, the white mangrove or batamanko.

The Rhizophora species of The Gambia are: Rhizophora racemosa G.F. Meyer, Rhizophora harrisonii Leechman, and Rhizophora mangle L.: all three species are found in the new world as well as West Africa. These three species are difficult to identify by vegetative characters. Fortunately, the May-June period of this study coincided with their flowering in The Gambia and it was found that they could be readily distinguished by floral characteristics, using the key of Keay (16).

Field sites that were visited in this mangrove study are shown on the following page.

Rhizophora racemosa is the pioneer species of The Gambia where it colonizes recently deposited alluvial soils up to the level of daily tidal flooding. Rhizophora racemosa is the species that forms the tall gallery forest along the lower Gambia River and bolons. It reaches a height of more than 40 meters and the trunks more than 1 meter in diameter. In common with the other Rhizophora species, R. racemosa has stilt or prop roots, and forms a dense mat of subsurface roots that support it in the unripe poorly consolidated soils where it grows. R. racemosa is the Rhizophora species that was found along the river from Banjul to Nianimaro (217 kilometers above Banjul), where, in the latter almost freshwater zone, the trees are small, 3-4 meters or less. R. racemosa was also the species in the forests that line the bolons except near Mandinari where low (less than 5 meters) forests of the three species were found side by side at approximately June ocean salinity--38 parts per thousand.

The tallest mangrove forests (R. racemosa) are found along the insides of bends in the bolons of the Gambia River where the slack water deposits alluvium. At several sites upriver from Yelitenda, the low

FIELD SITES VISITED IN THIS STUDY OF MANGROVES

Site	Approximate Distance Upriver (km)
Fajara	
Banjul - Bund	0
Lamin Island	5
Mandinari	10
Bintang	60*
Bwiam	82*
Darusalam	99*
Tendaba	100
Yelitenda	129
Bai Tenda	145
Elephant Island	145-156
Bambali	153
Kani Kunda Wharf Town	167
Dankunku Island	167
Kau-ur	183
Little Pappa Island	188
Jessadi Wharf Town	192
Njubdu Island	192
Pappa Island	193
Niamimaro	217
Kuntaur	230

* On Bintang Bolon

growing mangroves along the outer sides of river or bolon bends were also found to be R. racemosa. It appears that the older, higher elevation sides of the waterways on the stronger current sides of bends are poor soils for R. racemosa compared to the fresh alluvium on the slack water sides of the bends.

The band of low mangroves upland of the tall R. racemosa were also found to be R. racemosa, growing on higher elevation soil vacated by earlier generations of tall R. racemosa.

Rhizophora harrisonii. This species occurs in The Gambia along with R. mangle at the boundary between the Rhizophora and Avicennia mangrove stands. Giglioli and Thornton (10) state that at Keneba, R. harrisonii colonizes the fibrous clay recently vacated by R. racemosa, and that R. mangle grows in the higher elevation, sandier soils where it is often intermixed with the waterward edge of the Avicennia zone. R. harrisonii is intermediate in size between R. racemosa and the small form of R. mangle found in West Africa. A few specimens of R. harrisonii at Darusalam on Bintang Bolon were 7-10 meters tall.

Rhizophora mangle. This species occupies the drier and often more saline landward edge of the Rhizophora zone (Chapman, 4). Savory (31) found, in Nigeria, that it was a shrub no more than 4 meters high, which is in marked contrast to the species on the western side of the Atlantic Ocean in the Caribbean and Gulf of Mexico where it grows to be more than 20 meters high. The species on both sides of the ocean are likely the same. Dr. David Young of the University of Illinois has found chemical evidence, based on leaf flavonoids, that R. mangle in West Africa and Florida are the same species (personal communication).

It should be noted that the Gambian Rhizophora species are not rigidly substrate limited since all three, as well as Avicennia africana and Laguncularia racemosa, were found growing in higher than seawater salinities on the sandy tidal flats below the golf course at Fajara.

Rhizophora mangroves form fruits that germinate while still on the parent tree to form the pencil-shaped radicles or propagules that are the actual means of dissemination of the species. The propagules of R. racemosa attain lengths of 30-65 centimeters; those of R. harrisonii and R. mangle seldom exceed 20 centimeters. Propagules have no dormancy.

Rhizophora propagules may occasionally be planted by becoming imbedded in the substrate when they fall from the parent tree. Most often they are carried by tidal waters and put out roots where they become stranded. Rhizophora propagules float vertically and their large size prevents them from reaching many locations where there are obstructions such as fallen wood or branches, a band of seedlings, or pneumatophores of Avicennia.

Avicennia africana P. Beauv typically occurs on the higher elevation fibrous clay soils that have been vacated by Rhizophora racemosa, R. harrisonii, and R. mangle. Along the Gambia River and bolons, Avicennia africana varies greatly in size. In some areas, it remains a small tree or shrub, less than 7 meters tall, particularly on the inner edges of swamps. Where Avicennia occurs mixed with mature Rhizophora racemosa, as at Elephant Island, it is often a tall tree and grows to heights of over 20 meters and diameters approaching 1 meter. Johnson (14) found Avicennia africana growing upriver as far as Dankunku Island.

Avicennia forms a shallow mat of relatively large diameter roots from which grow up the thin finger-like pneumatophores. Avicennia roots do not form peat, i.e., the roots do not persist. Also, as Hesse reported (12), Avicennia roots, unlike Rhizophora, do not accumulate the pyrites and sulfur that are associated with acid sulfate soils. However, the lower horizons of Avicennia soils may form acid on exposure to air because of fibrous Rhizophora peat, rich in pyrites and sulfur, that was deposited at an earlier successional stage (Thornton and Giglioli, 42).

Avicennia africana bears fruit about 3-5 centimeters long, about the size of large flat beans. They have no dormant period. The seed-coat bursts when the fruit is moistened and the seed floats in water until it reaches a suitable substrate for germination.

Laguncularia racemosa (L.) Gaertn. occurs along the lower Gambia River and bolons. It was seen at Banjul (Bund Road), Fajara, Mandinari, Bintang, and Bwiam. Laguncularia occurs with the low growing Rhizophora species on soils that are probably more saline than those along the river or bolons. Laguncularia is uncommon and no specimens over 3 meters high were seen. Thus Laguncularia racemosa in The Gambia, as in Nigeria, is only a shrub or low tree (Rosevear, 29). This is in contrast to Florida where Laguncularia racemosa grows to more than 20 meters high and more than 45 centimeters in diameter (Teas, 37).

Laguncularia racemosa forms narrow flattened oval fruits about 2 centimeters long that have no dormant period. These small fruits float and are carried about by the tides much more readily than are the propagules of Rhizophora.

Salt Tolerance. Avicennia africana has a higher salt tolerance than do the Rhizophora species in The Gambia, probably because it has the capability of excreting salt through glands on its leaves. The droplets of concentrated salt solution so excreted form the small glistening crystals that are seen on Avicennia leaves during the dry season.

Rhizophora species differ in salt tolerance, although they do not excrete salt. It has been shown in Jamaica that R. mangle has a relatively high salinity optimum whereas in West Africa, R. racemosa has a low salinity optimum (Chapman, 4). In West Africa, R. racemosa has been reported as growing well in freshwater conditions, but that R. mangle is

found associated with higher salinity near river mouths or in the higher and more saline soils of the Rhizophora band upland of the R. racemosa (Savory, 31). Giglioli and Thornton (10) reported from literature that R. mangle does not occur at low salinities upriver.

Laguncularia was found in The Gambia growing in more saline soils near the river mouth or in the low growing Rhizophora zone. Laguncularia has salt-excreting glands on its leaves, which may be involved in its salinity tolerance. However, it is not as active in salt secretion as Avicennia.

Root Aeration. Mangrove species of The Gambia all grow in waterlogged soils which are very low in dissolved oxygen. The roots of all plants require oxygen and a variety of structural mechanisms for root aeration have been described in the literature. Scholander and coworkers (34) have shown that oxygen is supplied to the roots of Rhizophora mangroves by way of aerenchyma tissue (in the prop roots) through small openings called lenticels. Avicennia roots obtain oxygen through lenticels in the thin finger-like pneumatophores that project upward about 10-15 centimeters from the soil. Laguncularia has lenticels on the lower, trunk and, at some sites, has pneumatophores as well.

Because their roots are dependent upon obtaining oxygen (i.e., breathing) through the lenticels, mangrove trees are vulnerable to anything that covers these lenticel openings, such as flooding, thick petroleum residues or siltation. If the prop roots of Rhizophora are covered by water for a few weeks, the roots and thus the plant will die. Much less inundation is required to cover the pneumatophores of Avicennia. Athough normal spring tides and floods cover a substantial fraction of the prop roots of Rhizophora and completely cover the pneumatophores of Avicennia, this inundation is not lethal. The critical factor in tree survival under flooded conditions is the time involved. Diking around mangroves and pumping water to maintain a level above pneumatophores, trunk lenticels, and prop root lenticels for a few weeks is a means that real estate developers have used for killing mangroves to facilitate their removal (Teas, 39). The same technique applied in mosquito control impoundments has been sufficient to kill mangroves in 2 to 3 weeks, although the plants did not die for several weeks or months after the flooding (Provost, 27).

Succession. Rhizophora racemosa pioneers recently deposited alluvium, which is soft, unripe soil. The prop roots form a flying buttress structure base and below the surface of the soil, the roots immediately divide into innumerable hair-fine rootlets. The tree, which can be more than 40 meters high, has a trunk more than 1 meter in diameter, and weighs more than 15 metric tons, is thus supported on very soft soil by a thickly intertwined felt of roots. This root mat is the source of Rhizophora mangrove peat deposits. As Rosevear (29) noted, the Rhizophora root mat is so dense that it can be cut out in blocks, dried, and burned as peat fuel.

As Rhizophora racemosa grows, the thick mat of its roots gradually raises the soil elevation by displacement and by accumulation of additional alluvium, colluvium, particulate organic matter such as leaf litter, and dust. The slowly rising soil elevation results in reduced tidal flushing and may ultimately lead to the death of the pioneer R. racemosa.

Rosevear (29) has stated that R. racemosa can only reach its optimal size where it starts growing on newly deposited soft mud. It may be that only one crop of the tall R. racemosa can grow at a site before the root mat and elevation of soil level make conditions so unfavorable that a subsequent crop cannot succeed. Rosevear (29) reported that the soil of pioneer Rhizophora racemosa can only support new growth of the scrubby low form of Rhizophora species that are found behind the pioneers.

The period of time involved in the succession of R. racemosa is not known; however, the ages of R. racemosa can be roughly estimated from the girth/age table of Watson (44) for Rhizophora mangroves in Malaya. Based on the growth of known age trees in Malaya, and extrapolating, a 104 centimeter diameter Rhizophora racemosa that we measured would be in the range of 200-250 years old. This suggests that on an accreting shore, the pioneer stage of mangrove succession may last a few hundred years.

Between the high pioneer or mature R. racemosa and the Avicennia zone, there is a band in which R. racemosa, R. harrisonii, and R. mangle occur. These Rhizophoras, especially the R. mangle, may be intermingled with the waterward edge of the Avicennia africana zone.

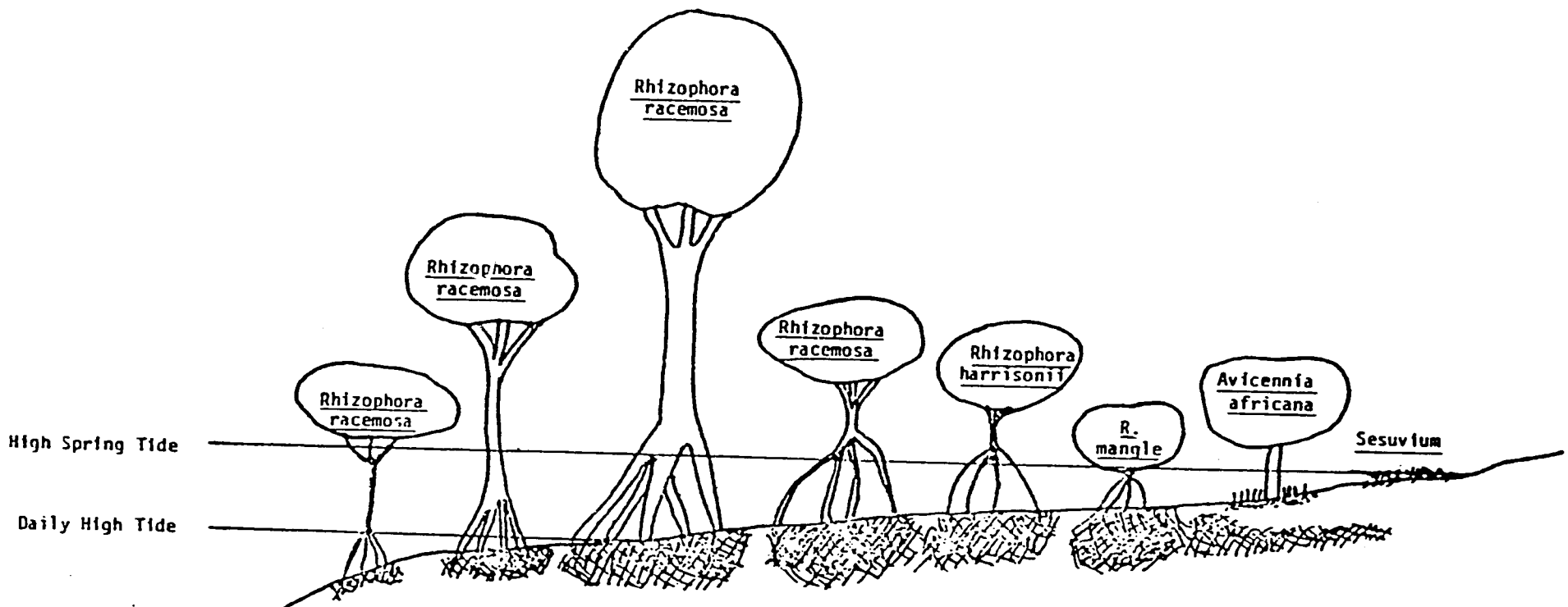
Avicennia replaces Rhizophora on the higher ground where the latter have died. The more open Avicennia forest with its dense field of upward projecting pneumatophores increases deposition of alluvium and wind blown and colluvial silt. In time, the soil level becomes too high for Avicennia to survive the dry season and the Avicennia is succeeded by a meadow of the low-growing herbaceous plant Sesuvium portulacastrum. Sesuvium in turn cannot survive the further soil buildup that follows and higher elevation barren flats are formed on which no plants grow.

In the succession from waterside soft alluvium to Avicennia and Sesuvium, there is an increase of interstitial (soil water) salinity. This increased salinity may provide a dry season stress that is involved in the succession of R. racemosa to Avicennia. In June 1981, the interstitial salinity of the soil at the Avicennia-Sesuvium interface at Darusalam was found to be 78 parts per thousand, the salinity of nearby Bintang Bolon was 45 parts per thousand on that date.

This pattern of mangrove succession is represented diagramatically in Figure A-6. Soil types, relative tidal levels, dry season soil salinity (Keneba) and soil pH are shown. What has been described and illustrated here is a classical succession, and, while examples of it can be found at many sites, it is subject to modification by local conditions of bank erosion, rate of sedimentation, freshwater runoff, etc., as noted by Giglioli and Thornton (10).

Figure A-6

SCHEMATIC SUCCESSION IN A RHIZOPHORA FOREST



Description of Soil (Giglioli & Thornton 10)	Young Rhizophora	Old Rhizophora	Avicennia	Sesuvium	Barren flat
Soil Series (Thomas et al. 14)	Bamba	Yelitenda	Yelitenda	Yelitenda	
Dry Season Soil Water Salinity $^{o}/oo$	40 (est.)	45	78	84	
pH Soil (Natural)	5	6.5	6	6.5	
pH Soil (Dried)	3	3	6	6.5	

Disease of Rhizophora. In 1978, Johnson (14) reported from field observations that there had been considerable mortality in the Gambian Rhizophora mangroves in recent years. This was especially evident because the 1972 1:25,000 scale aerial photographs that he used for his mangrove inventory between Yelitenda and Kau-ur showed no detectable damage. Indeed, some of his random field sampling plots in 1978 were found to be located in patches of total mortality or serious dieback that appeared normal in the 1972 photographs. He concluded that death and dieback of trees had occurred in the 1972 to 1976 period and suggested that it was probably associated with the abnormal drought conditions of those years. There are other indications that the development of the dieback is recent: Robert J. McEwan, Conservator of Forests of The Gambia, stated that he had first noted it 3-4 years ago (personal communication 1981).

Johnson reported very little dieback in Rhizophora mangrove forests with canopy over 20 meters high. He noted that there had been much dieback or complete death in the Rhizophora forest 7-20 meters tall; and that there was much dieback in the crowns of Rhizophora forest of less than 7 meters in height, but remarked that there had been some recovery in 1978. In 1981, we saw very few examples of live crown branches that could be interpreted as recovery.

Our field study in 1981 revealed large areas of dead and dying Rhizophora trees, especially in the taller than 20 meter class. The extent of the heavy kill can be seen dramatically in the 1980 1:25,000 scale false color infrared photographs where the canopies of live trees appear bright red and the trunks of dead trees were gray. These photographs show, for example, a large area near Darusalam on Bintang Bolon where there was an estimated 95% kill of the tall (20 meters plus) and medium size (7-20 meters) Rhizophora trees, as well as substantial kill of the low forest (less than 7 meters high). On-site inspection at Darusalam, where the three Rhizophora species occur, showed that all three were affected by dieback.

Dieback was seen at Fajara, Mandinari, and all points we visited along the river as far as large Rhizophora racemosa occurred, i.e., to Pappa Island, about 193 kilometers from Banjul. The few small Rhizophora seen at Nianimaro, about 217 kilometers upriver, did not have any obvious galls.

The Rhizophora trees affected by dieback all had galls and cankers on branches, trunk, and prop roots. These galls and cankers had a gnarled appearance. When galls were cut and examined, it became apparent that the abnormal growth was affecting tissues involved in transport. Inasmuch as the Rhizophora mangroves obtain their water and mineral nutrients as well as provide air to the subterranean roots through their prop roots, a disease that disrupts the prop root tissues is very damaging. It is generally found that Rhizophora mangroves have fewer prop roots as mature trees than they had at younger stages (8). A mature tree is probably not capable of developing new prop roots to

compensate for disease-damaged ones, although a young tree appears to do so. Indeed, some small trees (2-3 meters high) were seen that had one or more older prop roots with galls and several new prop roots without galls. In many cases, dead branches with brown leaves were seen on infected trees. In rare instances, entire trees had dead leaves. Some large trees that had died at least two years before showed extensive galls on the prop roots that indicated the dieback had affected them for a long time before they died. Galls were not found on first year Rhizophora seedlings.

The dieback disease symptoms in The Gambia are very similar to those encountered in Florida, where there is an endemic gall disease of Rhizophora mangle. One of us (H.J. Teas) has also seen galls on Rhizophora trees in Ecuador, Costa Rica, Puerto Rico, and Nigeria.

The Florida disease of Rhizophora was described in 1975 by Olexa and Freeman (24) who tentatively identified the causative agent as a fungus, Cylindrocarpon didymum (Hartig) Wallenw. The same authors reported in 1978 that they had consistently cultured Cylindrocarpon didymum from Rhizophora gall tissue and that they had demonstrated the pathogenicity of the organism on the basis of field inoculations of Rhizophora trees. The disease is slow to develop. Initial symptoms from inoculations of Rhizophora trees with laboratory cultured Cylindrocarpon didymum required 6 months to appear. Wounded and inoculated trees developed roughened calluses and galls from which the fungus could be readily isolated. Some unwounded inoculated trees developed thickened split periderm and swollen lenticels from which the fungus was also isolated. Control uninoculated trees did not develop galls or other growths. No galls were observed on Avicennia or Laguncularia mangroves.

Olexa and Freeman described the disease as producing galls on trunks, branches, and prop roots, primarily at nodal and wounded areas. Infected trees had thinned canopies and showed increased limb breakage due to wind. The gall disease of Rhizophora in Florida apparently kills some trees but is not a major cause of mortality even though in some areas 100 percent of the trees have galls. The galls varied from solid tumorous growths up to 20 centimeters in diameter to linear galls or cankers. Occasional branches on infected trees were dead. They reported that diseased tissue showed disruption of the vascular cambium and of the continuous phellogen layer of the periderm. In some instances, bark was observed to separate from the xylem. Disruption of secondary phloem was also noted. They found no role of insects in gall formation or transmission.

The genus Cylindrocarpon has 27 species and 6 recognized varieties. Members of the genus are known to be important parasites of trees, causing galls, cankers, and lesions on the woody parts of hosts in widely distributed parts of Europe and North America. No perfect state, i.e., sexual form, of Cylindrocarpon didymum has been found (Olexa and Freeman, 25).

Although the symptoms of the gall disease of Rhizophora mangroves in The Gambia and Florida are very similar, they differ in their lethal effect on the trees. It is possible that the same or a closely related organism is involved as causative agent in the two diseases. Rhizophora trees in The Gambia die with fewer and smaller galls on the trunk and branches than are found on surviving infected trees in Florida. However it should be noted that we are here dealing with a comparison of disease effects on large Rhizophora trees, i.e., R. racemosa in The Gambia and R. mangle in Florida. The two species have somewhat different growth characterisitcs in their respective ranges, so differences in disease symptoms might be anticipated even for the same pathogen.

The disease in The Gambia is widespread and serious. On checking several areas of Rhizophora racemosa gallery forest that had only occasional dead trees, it was found that all the nearby trees had galls or cankers, indicating that they were all infected. Here it should be noted that the low incidence of dieback in the taller than 20 meter Rhizophora forest reported by Johnson (14) compared with the obviously higher incidence in 1981 may simply reflect the slowness of disease development, i.e., that the tall trees, as well as those of intermediate and smaller size, were all infected in 1978 but it takes longer to kill the tall trees with their very large prop roots than it does to kill the smaller trees. The partial recovery of the low (smaller than 7 meters) Rhizophora forest at Darusalam reflects the more extensive regeneration in these areas where the trees had been killed earlier (Johnson 14). In addition to more time for regeneration, in the smaller than 7 meter mangrove zone a seed supply of the appropriate successional species, R. harrisonii and R. mangle, was available. Regeneration of high forest would be expected to be poor because the soil under large R. racemosa is higher elevation and has too thick a root mat for its own seedlings to prosper (Rosevear, 29). The R. racemosa high forest area would probably not be well supplied with seed of R. harrisonii and R. mangle because of distance from the source.

The obvious question with respect to the dieback is: why has a diseased condition that resembles one of minor significance in other parts of the world become so lethal in recent years in The Gambia? There are complex or interacting possibilities for this increase in the disease, such as combinations of one or more stress factors on the trees and simultaneously a more virulent pathogen; however, only the simple possibilities will be evaluated. They are:

1. That a new more virulent strain or organism is active in The Gambia. The appearance of new strains of plant pathogenic fungi is well known (Day, 7).

2. That some environmental change has occurred in recent years which has made the mangroves of The Gambia more susceptible to what had probably been present as a low level endemic disease. Plant pathologists have recognized that environmental factors or changes that make

conditions more favorable for the pathogen or that stress the host trees can play an important role in epidemics of forest dieback-decline diseases (Schmidt, 33). Environmental stresses that have been found to be involved in other epidemics of plant disease have been climatic change, edaphic factors, and biological factors (Ritem, 30). We have no definite information on the pathogen involved in the Gambian disease so cannot evaluate the case of pathogen-favoring environmental changes. However, the pathogen might be transmitted or develop more effectively under drought or other altered conditions than it does under normal conditions.

We have no information on biological factors that may have changed in recent years. One possibility is that an insect vector might have appeared that very effectively transmits the infection that was poorly transferred in earlier, pre-insect times. Although Olexa and Freeman (25) found no evidence of insect transmission, such a possibility cannot be excluded.

There is a suggestion in the literature (Reark, 28) that the occasional localized high incidence of the gall disease of Florida Rhizophora mangroves may indicate that the mangroves at the particular location are stressed, that is, that the incidence of disease may only become high where the trees are environmentally stressed. He suggested that such high disease incidence forests appear to be suffering from a reduction in tidal circulation or to be growing on marl soils which are a poor substrate for Rhizophora.

Whatever stresses are postulated, they cannot have been responsible for a major epidemic in The Gambia for at least the last century. There are many large stands of Gambian Rhizophora racemosa almost certainly more than 100 years old that speak to the absence of such destructive diseases as the present one in their lifetimes.

The considerations discussed here are based on drought as the stress, but might be related to any other recent widespread stress. It is here assumed that a drought has existed in The Gambia for the last 14 years. But environmental stress factors that may have developed in recent years could be of two types: those that relate to drought and those that are based on other factors.

An effect of the drought could be that with delayed and reduced rainfall, there would be longer than normal periods without rain or flooding. During such times, the roots of mangroves might be exposed to higher salinity than is normal because of lowered water tables and the longer time for salinity in the root zone to build up by evaporation. It has been shown that increases in salinity cause a reduction in transpiration and growth in Rhizophora and that excessive salinity can kill all species of mangroves (Teas, 39). Giglioli and King (11) found

increased salinities in mangrove soils in the Keneba swamp as the dry season progressed. Even though a drought with delayed first rain, coupled with a series of neap tides might make the soil water along Bintang Bolon saline enough to stress Rhizophora, it is difficult to see that such a mechanism is adequate to also explain stress-based disease killing of tall Rhizophora at Elephant Island where the maximum salinity of the surface water during an annual cycle is about 21 parts per thousand compared to about 45 parts per thousand at Keneba.

Although drought induced hypersalinity does not seem to be adequate as a special stress factor for mangroves in recent years, an additional series of neap tides during which the mangroves were not tidally inundated would provide an increased opportunity for reduced sulfur compounds in the surface layers of fibrous soils to become oxidized to sulfuric acid. Thomas et al (41) and Johnson (14) have stated that sulfuric acid from such soil oxidation would readily kill mangroves. Even though the acid formed were not of sufficient concentration to kill the trees, it might stress them. Thornton and Giglioli (42) reported both young and old Rhizophora soils in which pH's dropped to 2.5 on drying. Although most Rhizophora soils are ordinarily wet, it may be that some drying and acid formation at the soil surface occurs during neap tide series even in years of normal rainfall. And some root deterioriation from acid might occur during normal years, but not reach a "clinical" level. However, the additional exposure of soils because of drought might cause excessive acid to be formed which could stress the plants. A basis for this suggestion is that in the Avicennia zone at Darusalam and Mandinari, the upper halves of Tympanotonus fuscatus snail shells lying on the mud were found to be eaten away. Dissolution of mollusc shells occurs at pH of 5-6 or lower (Boyé et al, 3). The soil at Mandinari was found to have pH of greater than 7 (measurement courtesy of Department of Water Resources Water Quality Laboratory at Abuko). The soil consisted of a mix of clay and a dense Rhizophora root mat. The finding that such a soil, with a pH above neutrality but with acid sulfate potential (Thomas et al, 41), has no effect on the lower parts of the shells in contact with it, but that air-exposed upper surface becomes acid enough to completely dissolve the exposed parts of the shells, suggests that there are micro aspects of soil chemistry that may be very important to mangroves.

If trees were weakened by acid deterioration of their fine surface roots, a disease that disrupted a portion of the conducting tissue in the prop roots might interact to convert an endemic disease like the Florida one into a serious epidemic. A corollary of this argument is that young pioneer Rhizophora at low soil elevations should not be stressed and therefore not suffer dieback. No check was made of this possibility. A point in favor of the drought-induced acid stress of Rhizophora is that it would apply equally to Mandinari and Elephant Island since the mangroves at both locations are growing in a potential acid sulfate soil (Thomas et al, 41).

One type of stress that is known to occur in Gambian mangroves is that involved in the normal slow succession from R. racemosa to R. harrisonii and R. mangle and from them to Avicennia africana. These successional changes are progressively associated with increases in soil elevation, decreased tidal flushing, increased soil salinity, and increased soil drying.

The general features of mangrove succession from young Rhizophora at the edges of the river and bolons to Avicennia further upland appears to be true at least 167 kilometers upriver at Dankunku Island (maps of Johnson, 14). Thus, the subtle physiological aspects of succession must be able to operate over a wide range of salinity. It should be noted that the soils on which Rhizophora mangroves are growing at Dankunku Island are potential acid sulfate series (41).

A possibility for mangrove stress that involves soil elevation, and therefore accelerated succession, is the contribution of dust. In areas remote from roads, we found reddish dust on mangrove leaves, which we assumed was fallout of Sahara material that had been carried by Harmattan winds. If the amount of such Sahara dust has increased because of the drought years, the effect might be cumulative. Giglioli and Thornton (10) showed an old Rhizophora soil at Keneba as having a 15-30 centimeter sand layer at the surface which suggests that an important component of soil elevation buildup in Rhizophora mangroves is dust. However, Thomas et al (41) did not report such a sand layer in their old Rhizophora soil samples from above the proposed barrage, so surface sand buildup is not a universal feature of older Rhizophora soils.

In addition to possibilities of mangrove stress induced by a longer dry season (drought) through mechanisms of salinity, acid production, or buildup of Sahara dust, the mangroves might be stressed by an increased silt burden from the Gambia River. Increased silt could derive from increased clearing of land with the associated erosion upriver in Senegal and Guinea. Since alluvial deposition is one of the components in the buildup of soil elevation that is involved in mangrove species succession, it may be that trees "on their way out" because of accelerated succession are more susceptible to the disease. Data on the sediment load of the Gambia River were not available for the period of years required to evaluate this possibility.

Fragmentary evidence on the rate of increase of disease in recent years suggests that a large fraction of the tall Rhizophora trees that are already infected will die within the next 3 to 5 years.

The tall Rhizophora racemosa forest in The Gambia has not been harvested so far as we could see. It had the gross appearance of an overmature forest, i.e., one where weakened old trees are dying from natural causes. The idea was advanced by one of the team that the mangrove dieback might be merely a natural way for the ecosystem to recycle the energy of overmature trees, and not a specific epidemic disease. The

arguments against this hypothesis are convincing: the dieback disease attacks trees of all sizes from the age of 2 or 3 years, so could hardly be categorized as a selective means of harvesting over-age trees. Also, the disease cannot be a general West African system for recycling over-age trees: Rhizophora forests in the Niger delta of comparable size show no similar natural recycling system.

It appears likely that the reason for the epidemic of Rhizophora dieback disease is either some physiologically subtle stress factor that makes the trees more susceptible to an ordinarily benign disease, or a new virulent disease has appeared in The Gambia that may pose a threat to all the Rhizophora mangrove forests in the world.

Biological Hazards to Wood. Rhizophora wood from trees that have been killed by dieback is subject to several types of biological attack that reduce the value of the wood.

Beetle larvae from eggs laid in the bank bore into the trunks of standing and fallen dead trees. One to two centimeter diameter emergence holes of the adults were commonly seen. The common type of beetle that makes such round emergence holes is the long horned beetle of the family Cerambycidae. It should be noted that another family of beetles, the Buprestidae, also bores into logs and fallen trees. Johnson (14) noted occasional bored tunnels in stacked fuelwood. The female cerambicid lays eggs in crevices in the bark of dead trees. The entrance hole the larva makes as it bores into the tree is small and not likely to be seen. The larva spend months or sometimes more than a year boring in the trunk before it pupates and later emerges as an adult by way of the round hole it prepared as a larva. Cerambycid beetles rarely infest any but dead wood. The trunks of several trees that showed multiple emergence holes were chopped open and found to be rotten and useless.

The number of emergence holes we saw in dieback-killed Rhizophora wood indicate that a large population of cerambycids is already present and that their number is increasing rapidly. Female cerambycid beetles oviposit on trees with bark much more readily than they do on debarked or split wood or sawn timber. The strategy for harvesting dead trees and even temporary field storage of felled live trees will require consideration of cerambycid beetle biology. Bore holes in the heartwood of Avicennia trees indicate that cerambycids attack them as well as Rhizophora.

Shipworms or Toredos. Prop roots of dead standing Rhizophora and fallen trunks of Rhizophora were found to be infested with shipworms or toredos (Teredinidae)--in some cases riddled with them. Toredos are a potential hazard for downed wood that is reached by tidal waters. As Johnson (14) noted, some toredos live in brackish water areas so there is no assurance that wood above the barrage could be safely stored under water. However, while toredos ruin trunks for sawn timber, light infestation should not pose a serious problem for fuelwood use.

Wood Rotting Fungi. Dead Rhizophora wood begins to rot within months if it is wet, but there appear to be no special problems with fungi if the wood is stored dry. Bracket fungi were a common feature of long-dead dieback-killed Rhizophora trees. By the time such fruiting bodies of the fungi appear, the wood has long since lost all value.

Upstream Plant Species

Present Species. Above the barrage site, the river has decreasing saltwater influence. From Elephant Island upriver shorelines are increasingly seen with dense prairies of Phragmites which is tolerant of brackish water. The acacia-like shrub Drepanocarpus lunatus is more frequently seen as are dwarfed Phoenix palms. Farther upriver, the freshwater grasses and palms increase as the mangroves are smaller and disappear, probably between Nianimaro and Kuntaur. In this area, there appear several "grassy" species such as Cyperus, Echinochloa, and Typha, and at the riverbank or a short distance inland are Borassus, Elaeis, Phoenix, and Raphia palms. It is reported (Coode & Partners, 6) that farther upriver Pandanus grows and that it has roots which collect silt and help to stabilize the riverbanks.

Species After Barrage. When the barrage is operational, the water upstream from Yelitenda will be fresh all year. A parallel situation occurred in a river studied by Joshi and Shinde (15). They reported on changes in the flora along the Vashisti River in Western India. Twelve years before their study, the tail waters from a large hydroelectric plant were diverted into the Vashisti River so that it flowed fresh water 12 months of the year instead of only during the months of the monsoon season. Formerly, there had been well developed mangrove forests 32 kilometers upstream from the Arabian Sea. At the time of their study, the mangroves were continuing to grow among the freshwater reeds and grasses, but competition from freshwater hydrophytes seriously limited mangrove regeneration.

The plant species that will become established intitially in the present mangrove zone above the barrage after it is completed will probably be those that have some tolerance of salinity, such as the Phragmites, Drepanocarpus, and Phoenix and Raphia palms. Over the long run, conditions above the barrage will be favorable for freshwater floodplain grasses because of the permanent freshwater environment and the anticipated longer hydroperiod.

The freshwater marsh-swamp vegetation already present upriver comprises a wide array of species, much more diverse than are found in the present saline and brackish mangrove zones.

The species that are presently growing upriver that are likely candidates to colonize newly available freshwater habitat created by the barrage are shrubs and grassy species, none of which shows promise as replacement for the wood of the mangroves. Even though the mangroves

may survive for a period of years, it is not anticipated that they will regenerate and provide a continuing source of wood. Under conditions of greatly reduced salinity, mangroves do not prosper. The Rhizophora racemosa at Nianimaro 217 kilometers upstream (salinity one part per thousand in June 1981) were small, apparently not very competitive with the reeds and miscellaneous grasses and shrubs at that low salinity. It should be noted that the one part per thousand salinity is probably the highest value attained during the year at this part of the river under the present natural conditions.

Potential Wood Crops

It would be desirable to replace the wood production potential of the mangroves above the barrage with other tree species, ones that will grow in fresh water or with intermittent flooding. Rapid growth and tolerance of freshwater inundation would be required as well as the ability to compete with an array of freshwater hydrophytes.

The subtleties of interspecies competition are not well enough known to predict which West African swamp forest trees or exotic trees would prosper in this environment. Three species that grow in freshwater swamps or wet areas are suggested as possibilities in Table A-11. These selected species are reported to be fast growing, have wood that is suitable for fuel, and can withstand wet soil and freshwater flooding. There are, no doubt, many others that should be considered.

Evaporation and Transpiration

The evaporation from the impounded water above the barrage is expected to exceed the flow of the Gambia River from mid-December to mid-June (Coode & Partners, 6). With large water losses already anticipated, it is important that any trees planted along the river above the barrage for wood production be ones that do not waste water by excessive transpiration. Comparable data on transpiration by a range of plants are difficult to find because methods differ and few investigators make broad species comparisons. The data in Table A-12 show temperate species, but a clear trend is evident: grasses in this series transpired more than five times the amounts that trees do. No data were available on grassy freshwater hydrophytes except a comparison of transpiration rates in sawgrass and Melaleuca (Woodall, 45) which showed that the two were approximately equal. After the barrage is operating and if the mangroves are replaced by reeds and grasses, the water losses may be substantially greater than those calculated by Coode & Partners. In any case, it seems likely that to the extent that productive trees replace the almost worthless reeds and grasses, transpiration losses will be reduced.

Table A-11

THREE POTENTIAL TREE SPECIES FOR PLANTING ABOVE THE BARRAGE

Family	Species	Common Name	Geographical Origin or Distribution
Malvaceae	Thespesia populnea Soland:	Seaside mahoe	Pantropical
Myrtaceae	Melaleuca leucadendron L.	Melaleuca, Cajeput	Australia
Leguminosae	Acacia nilotica (L.)	Egyptian thorn	Africa

Notes:

Thespesia populnea. Is adapted to river and alluvial flats subject to flooding (Sturrock, 36).

Melaleuca quinquenervia (leucadendron). Johnson (14) recommended investigation of Melaleuca as a possible crop for saline soils not required for agriculture. A few trees of Melaleuca sp. are growing near the Banjul High School. Melaleuca has some salt tolerance but typically grows upland of mangroves, as a "back mangrove." Melaleuca grows rapidly in Florida. In the Camau Peninsula of Vietnam, Melaleuca has been harvested as a pole crop (H.M. Smith, personal communication). Melaleuca is adaptable to a wide range of soils from dry to swampy (Sturrock, 36). In the Florida Everglades, Melaleuca competes successfully with the native sawgrass (Cladium jamaicense). It grows well in Florida at marshy sites where the soil is periodically wet or even inundated continuously for years (H.J. Teas, unpublished). Melaleuca is notably fire-tolerant. Melaleuca has been criticized because it spreads rapidly in some areas, and has been alleged to cause allergic responses in some persons; however, systematic experiments have shown that it is not a significant source of allergens (Lockey et al, 17). Claims that Melaleuca dries out swamps by excessive evaportranspiration have recently been countered (Woodall, 45).

Acacia nilotica, an African tree, was characterized by the National Academy of Sciences study as tolerating several months of flooding.

Table A-12

TRANSPIRATION RATES OF PLANTS *

Species	Grams per Square Decimeter per Hour
Herbaceous Plants	
Corn (*Zea mays*)	2.5
Sarghum, kafir (*Sorghum vulgare*)	2.2
Sorghum, milo (*S. vulgare*)	4.3
Woody Plants	
Box elder (*Acer negundo*)	0.6
Buckey (*Aesculus glabra*)	0.7
Maple (*Acer saccharinum*)	1.0
Oak (*Quercus rubra*)	0.8
Orange (*Citrus sinensis*)	0.2
Peach (*Prunus persica*)	0.7
Pecan (*Carya illinoensis*	1.07
Pine (*Pinus ponderosa*)	0.2
Spruce (*Picea engelmannii*)	0.2
Sycamore (*Platanus occidentalis*)	0.8
Walnut (*Juglans nigra*)	0.09
open water pan @ 30-33°C	0.23-0.28

* From Spector (35).

Methods

Salinity of surface and interstitial waters was measured using a direct reading, temperature compensated refractometer, American Optical Company No. 10419.

A chain saw for felling trees was loaned by the Gambia Department of Forestry. Trees were cut at two sites: along a bolon upriver from Yelitenda, and at a site along a bolon across the river from Tendaba.

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Appendix 5-B

PROCEDURES AND COST OF PLANTING MANGROVE SITES ALONG THE GAMBIA RIVER AND ITS BOLONS

Procedure

Natural regeneration can be supplemented by hand-planted materials, i.e., propagules. A progagule has leaf buds at the top and several root primordia at the bottom. When the lower end of a propagule is imbedded in the mud or soil, roots begin to develop within a few days or weeks and the leaf shoot opens into leaves. Propagules are "mature" and ready to grow when they fall from the parent tree. They float in the water and can put out roots when they come to rest on the soil or soft mud. The largest crop of propagules is probably available during the late summer and fall.

Hand-planted propagules will grow if planted in appropriate places. Propagules should be planted about 1/4 their length in the soil, although planting depth is not critical. Propagules can be stored in partial shade with their lower ends in water (as in partly water-filled buckets) for a few weeks. However, when roots become long enough to break in handling, seedling survival after planting is impaired. A mixture of three Rhizophora species should be used for planting.

Mangrove propagules should be planted 1/2 meter apart for 10 meters back from the water. Thus, for each 10-meter section of shoreline, 400 propagules should be planted.

For the next 40 meters back from the water, propagules should be planted one meter apart. Thus, for each 10-meter length of shoreline, 400 more propagules will be required. In some cases, planting to a distance greater than 50 meters inland may be desirable.

Costs

The well-developed mangrove forest extends up the Gambia River for approximately 167 kilometers (Dankunku Island)	= 340 km of shoreline
Assuming the bolon shoreline is three times as long	= 1,020 km of shoreline
Total	1,360 km of shoreline

The cost of collecting 800 propagules is estimated to be	160 bututs
The cost of planting 800 propagules is estimated to be	120 bututs
Total	2.8 dalasis

1,360 kilometers = 136,000 ten-meter sections
136,000 x 2.8 dalasis = 380,800 dalasis

Estimated cost of replanting to compensate for block failures and damage due to logging, etc. is D50,000.

In five years, the cut of mangrove will be 500,000 cubic meters. Therefore:

$$\frac{D430,000}{500,000} = \text{a planting cost of 0.86 dalasis per cubic meter logged.}$$

Appendix 5-C

MANGROVE SOILS

Mangroves have developed under a rather complicated ecological system discussed elsewhere in this report. The study of mangroves has been long neglected. Even more so the study of mangrove soils. There are only a handful of soil scientists who have devoted their efforts to studying and understanding mangrove soils. An international symposium about these soils was held at Wageningen, The Netherlands, in 1972 and another one in January 1981 at Bangkok, Thailand, where the world's knowledge on acid sulphate soils was compiled. Most mangrove soils are potential acid sulphate soils, even though mangroves may have long disappeared from their surface. Although there are some 45 million hectares (1) under mangrove throughout the world, their potential value has not been generally recognized. Thus, there has been little incentive to study mangrove soils.

Area of Potential Acid Sulphate Soils

There are potential acid sulphate soils in many parts of the world. An estimated 5.4 million hectares exist in Southeast and East Asia, and over 6.6 million hectares are located in Africa. Table A-13 gives the distribution in Africa. There are about 375,000 hectares of potentially acid sulphate soils in The Gambia, of which 12,900 hectares have been mapped in the project area.

Table A-13

POTENTIAL ACID SULPHATE SOILS IN AFRICA

	Hectares (000)
Senegal	975
Gambia	375
Guinea Bissau	1,175
Republic of Guinea	825
Sierra Leone	500
Liberia	125
Ivory Coast	25
Ghana - Togo	150
Nigeria	1,550
Cameroon	250
Chad	700
	6,650

Source: World Distribution of Acid Sulphate Soils by A. Kawalec (1973) as quoted by M. Khouma and M. Toura - Djibelor Rice Exp. Sta., Senegal.

Characteristics of Potential Acid Sulphate Soils

Potential acid sulphate soils and acid sulphate soils are found in the low lying coastal lands in the tropics and are generally very unproductive or not suited for agriculture.

Acid sulphate soils are soils which, within the first 50 centimeters of their profile (occasionally deeper), show a very low pH, i.e., generally below pH 3.5 or 4, when they are dried. This situation is directly caused by sulfuric acid formed by oxidation by pyrite (FeS_2), or rarely of other reduced sulfur compounds.

Potential acid sulphate soils are poorly drained and highly pyritic with a nearly neutral or slightly acid reaction in the field. They become acid sulphate soils if pyrite oxidizes after drainage., i.e., when they dry up and are exposed to air. Although a low pH is detrimental to most cultivated plants, these soils are often suitable for flooded rice as they are generally level, well supplied with plant nutrients, and often have a favorable hydrologic setting. Flooding these soils for rice cultivation, helps to raise the pH by the reducing action caused by the saturation with water.

Formation of Potential Acid Sulphate Soils

Pyrite deposits are formed by the interaction of sulfur compounds and iron in the sea water, and organic matter. All are plentiful in tropical tidal marshes, with the organic matter supplied by mangrove roots. The pyrite content of mud in the tidal marshes generally varies from 2 - 6%. Data for typical profiles in the Thomas et al (3) report for the two soils in the project area in The Gambia, judged to have acid sulphate potential, show a high for the Bamba series of 2.70% of pyritic sulfur in the 18-43 centimeter layer in the one profile presented. The high for the three profiles of the Yelitenda series is 2.42% in the 28-100 centimeter layer, 2.08% in another profile in the 57-100 centimeter layer, and in the last 0.64% in the 28-70 centimeter layer.

Formation of pyrite deposits takes place mostly under alternating aerobic and anaerobic regimens. Van Breeman and Pons (4) discuss three profile zones in mangrove soils:

Zone I: A predominantly aerobic surface layer, normally several centimeters to several decimeters thick.

Zone II: A predominantly reduced zone with limited, periodic aeration due to tidal fluctuation.

Zone III: A predominantly reduced zone below the lowest ground water level.

Zone II is where the tidal regimen is strongly felt and pyrite deposits are principally formed. These swamps are normally covered with dense stands of Rhizophora. Avicennia forests contain relatively less pyrite deposits. It is not known whether this is due to the lower organic matter production of the Avicennia root system or a reduced tidal regimen. Low pyrite content in more recent coastal sediments may be due to a lack of time for formation as it is estimated that the time needed to deposit one percent of pyrite may vary from 50 to 1,000 years.

Pyrite sediments in temperate regions often contain sufficient calcium carbonate to counteract acidification upon pyrite oxidation, but in tropical tidal marshes, the carbonate contents are low or nil. The carbonate alkalinity (HCO_3^-) produced during sulphate reduction is normally not conserved in the sediments by precipitation of calcium carbonate (although groundwaters in the tidal marshes commonly are saturated with calcite), but carried away by tidal action. This separation between immobile potential acidity (pyrite) and mobil alkalinity (HCO_3^-) is crucial for later acidification (4).

Development of Acid Sulphate Soils

Aeration of potential acid sulphate soils and subsequent acidification starts after the water table stays below the pyritic zone for several weeks. This can happen through natural processes over a longer period of time or more quickly by empoldering and draining. After drainage, the physically unripe soil will crack and air will penetrate. The overall chemical reaction resulting is:

$$FeS_2 + 7/2\ O_2 + H_2O \dashrightarrow Fe^{++} + 2SO_4^{=} + 2H^+$$

The chemical oxidation is greatly speeded by the presence of microbes of the genus Thiobacillus. Soils thus oxidized develop conspicuous yellow mottle, unless organic matter is extremely high, caused by a mineral form called Jarosite [$KFe_3(SO_4)_2(OH)_6$]. This mottle can be observed on soil material brought from lower layers in the mangrove areas in The Gambia, and on the surface of bunds constructed to protect rice fields.

If young acid sulphate soils are again submerged, they may again revert to nearly neutral potential acid sulphate soils, especially if the organic matter content is high. In Sierra Leone, it was found to take one to two years under tidal influence to accomplish this reversion. However, it would take longer for older acid sulphate soils.

Soil Stability and Erosion of Mangrove Soils

In disucssing the soils of the project area and of The Gambia in general, terms are used by the soil scientist, which do not occur very often in his vocabulary, i.e., ripe, half-ripe, and unripe soils. The big majority of the soils in the world are "ripe" soils, while the

mangrove soils mapped in the project area are either unripe or half-ripe. The field observation and description to classify a soil as ripe, half-ripe, or unripe is as follows:

Unripe: Can easily be squeezed through the fingers. Is sticky, but sometimes non-sticky. Is non-plastic and unsuited for general construction work or mechanical cultivation.

Half-ripe: Flows with moderate difficulty between the fingers. Is slightly sticky to sticky. Is slightly plastic. Little problem for construction work. Cultivation limited to light machinery.

Ripe: Squeezed through the fingers with great difficulty. Is non-sticky to slightly sticky and plastic to very plastic, provided there is sufficient clay content. (All sandy soils are ripe soils.) Have no problem for construction work or cultivation.

The Bamba series, an unripe soil, is formed in the tidal flats and its parent material is tidal muds. It will not support the normal weight of a man, unless the roots of vegetation like mangroves are present. There are 2,400 hectares of this series.

The Yelitenda covers 10,500 hectares. It is half-ripe throughout the profile studied, i.e., down to 100 centimeters. This soil also has formed from tidal muds, but generally is in a slightly higher position occupying the upper zone of the tidal flats.

Both soils are very similar morphologically with the Yelitenda series slightly better drained in its surface, thanks to lesser tidal influence. Both soils are the mangrove soils, the Bamba series mostly occupied by Rhizophora, and Yelitenda by Avicennia, although the latter may support either species. Both are sulphidic and their profiles show many fine roots of mangroves throughout.

Thanks to the mangrove root system, these soils are kept in place. Otherwise, they would be highly erosive and fluid, especially the Bamba series. Some of the bolons have an almost rectangular profile with very steep banks, but they are kept in place by the mangrove root system. The root system of Avicennia will disappear very rapidly if the plants are cut, because it is too fine. The root system of the Rhizophora will persist under anaerobic conditions for a long time. Mature Rhizophora roots may extend about 100 centimeters into the soil. Experience has shown that areas where wood cutters cleared a path in Rhizophora, the soil becomes quite fluid and will not support any weight whatever while under water. Should mangroves be removed, some erosion and bank slumping can be expected.

Johnson (2) suggests that, if systematic harvesting operations of the mangroves is undertaken, a strip should be left along embankments as a protection. This is certainly a sound suggestion, provided the mangroves remain alive, fully or at least in part. Leaving a strip would make it more difficult to harvest these trees at a later date. Therefore, where conditions remain favorable for the growth of mangroves, replanting them would be an alternative. Thus, the old root system would be replaced or reinforced by the root system of the new plants. However, if these soils are no longer under saltwater regimens, it is expected that the mangroves will receive increased competition from tall reeds like Phragmites karka and Echinochloa pyramidalis, which also have an extensive and tough root system, thus reducing erosion and increasing stability of these soils. However, the root system of these reeds is by no means comparable to the mangrove root system. Therefore, an increase in erosion and bank slumping must be expected. Another problem of these grasses is that they are a serious obstacle to rice cultivation, whenever they are well established.

It should be mentioned that the Pakuba series of which 7,500 hectares were mapped is also half-ripe and the Sassony series covering 5,800 hectares in the project area is half-ripe below 50 centimeters. Both soils are flood plain soils just above the normal tidal limits. They lack the fibrous root matting found in the mangrove soils. They are non-sulphidic.

Harvesting Operations on Mangrove Soils

As discussed above, the soils classified as Bamba series are unripe and have extremely low carrying capacity. Thus, it is difficult for people trying to harvest the mangroves to gain a footing for work. The Yelitenda series is half-ripe, thus will support some weight. However, field observation indicates that regular movement on foot on these soils is extremely difficult. To gain a better footing for harvesting work, it may be necessary to work from boards or other materials placed on the ground, or devise some simple mats made out of branches and/or palm leaves to support a man while working. The principle would be similar to that involved in the use of snowshoes.

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Appendix Six

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Appendix Seven

TEAM MEMBER RESPONSIBILITIES

TEAM MEMBER	SCOPE OF WORK REQUIREMENT
A. Environmentalist/Study Coordinator	a. Work with the Silviculturalist, the Soils Scientist, and Logging Engineer to determine the impact of the alternatives proposed for harvesting the mangrove both upstream and downstream of the bridge/dam;
	b. In doing the above, the Environmentalist shall examine the effects of soil acidification in the pool area on the mangrove resource and on the habitat of fish, birds, and other forms of aquatic, plant, and animal life;
	c. Work with the Soils Scientist and the Logging Engineer to determine the effects of the harvesting alternatives on river bank stability, water quality, habitat, etc.;
	d. Work with the Economist and the Anthropologist to analyze the impact of disruption of the habitat of aquatic, plant, and animal life on the diets and incomes of surrounding populations;
	e. Work with the Forest Products Technologist to analyze the impact of effluents of the various processing alternatives; and
	f. Work with the Anthropologist and the Regional/Rural Planner to analyze the environmental impact of potential labor influx into the area around Yelimida, particularly in view of labor already attracted to the area by employment opportunities created in connection with construction of the dam/bridge.
B. Logging Engineer	a. Analyze harvesting alternatives including start-up and O & M costs, types of equipment, labor requirements, etc. for both water and land-based operations;
	b. Analyze transport systems such as barge or truck through the entire harvesting-processing-marketing chain;
	c. Analyze storage requirements;
	d. Work with the Forest Products Technologist and other members to review labor-intensive and appropriate technology approaches;
	e. With the Soils Scientist, review alternatives for water management behind the dam to facilitate harvest;
	f. Review processing/utilization alternatives such as charcoal production, direct energy applications, wooden agricultural bearings, cross ties, textile shuttles, etc.; and
	g. With respect to all of the above, the consultant shall give emphasis to the Mangrove in the area above the dam; however, to the extent that sustained yield management of the downstream resource is possible from a silvicultural point of view, he shall also analyze equipment, labor, transport, processing, and marketing requirements for that resource.

TEAM MEMBER	SCOPE OF WORK REQUIREMENT
C. Silviculturalist	a. Work with Soils Scientist and Environmentalist to analyze alternatives for water management behind the dam to prolong the survival of the Rhizophora sp. following dam closure;
	b. Review results of ODA-financed inventory of mangroves in the downstream areas to determine volume, mean annual increment, conditions of natural regeneration, etc. of the resource;
	c. Analyze alternatives for management of downstream mangroves for sustained yield exploitation consistent with needs to preserve wildlife and aquatic habitat and maintain stability of river banks; and
	d. Study the possible replacement of the mangroves with other species of trees.
D. Forest Economist	a. Work with the Forest Products Technologist, the Logging Engineer, and other team members to carry out macro- and micro-economic and financial analyses of the alternatives identified for harvesting and processing the mangroves, both upstream and downstream of the proposed dam;
	b. Use benefit/cost ratios, financial and economic internal rates of return, or other appropriate measures in connection with the above analyses;
	c. Estimate the recurring costs accruing to the Government of The Gambia as a result of the alternatives;
	d. Work with the Forest Products Technologist and the Logging Engineer to determine the costs of transportation or other infrastructure improvements required by the alternatives;
	e. Analyze markets for the various potential products, both domestic and foreign;
	f. Analyze the foreign exchange impact of the harvesting and processing alternatives;
	g. Analyze sources of financing for capital investments required by the alternatives, including domestic and foreign, commercial and concessionary;
	h. Work with the Anthropologist to examine the differential employment/income effects of the alternatives proposed for harvesting and processing; and
	i. Examine effect of inclusion of the downstream resource on the economic feasibility of exploiting the upstream resource.
E. Forest Products Technologist	a. Work with Logging Engineer to analyze alternative uses of mangrove, such as cross ties, charcoal, fuelwood, power generation, etc.;
	b. Identify foreign exchange and other capital investment costs, O & M costs, manpower requirements and costs, etc.;
	c. Work with the Logging Engineer, the Economist, and the Silviculturalist to confirm the adequacy of the supply of mangrove (upstream and downstream) for the uses proposed;
	d. Work with the Economist to determine the economic and financial feasibility of the alternatives proposed;

TEAM MEMBER	SCOPE OF WORK REQUIREMENT
	e. Analyze requirements for supporting infrastructure such as power systems, ports, roads, warehousing, etc. and work with the Economist to determine their costs;
	f. Analyze labor requirements of various alternatives and work with the Anthropologist and the Forest Economist to determine the source and adequacy (number and skills) of labor;
	g. Review labor-intensive and other appropriate technology approaches for processing; and
	h. Analyze options for locating the processing facilities.
F. Anthropologist	a. Work with the Forest Products Technologist and the Logging Engineer to determine sources of labor for the harvesting, processing, and marketing alternatives identified;
	b. Analyze adequacy of labor sources in terms of numbers and skills and in view of competing requirements for labor in connection with the construction of the proposed bridge/dam at Yelitenda and peak season agriculture;
	c. Work with the Economist to determine the differential impact of alternatives proposed for harvesting, processing, and marketing on population groups such as the rural poor, the urban poor, etc.; and
	d. Work with the Regional/Rural Planner to analyze requirements of the various alternatives for supporting social infrastructure.
G. Soils Scientist	a. Work with the Silviculturalist and the Environmentalist to determine the impact of sustained yield exploitation of the downstream resource on river bank stability;
	b. Work with the Environmentalist, the Silviculturalist, and the Logging Engineer to explore alternatives for water management above the dam with a view toward prolonging the life of the upstream resource; and
	c. Analyze the impact of exploitation of the mangrove above the dam area on river bank stability, soil acidity, etc.
H. Regional/Rural Planner	a. Work with the Logging Engineer and the Forest Products Technologist to determine best locations for the various processing alternatives such as tiemills, etc.;
	b. In cooperation with other appropriate team members, analyze the impact of the various processing alternatives on those locations in terms of increased demand for housing, health, and other social services; and
	c. Analyze in particular the impact on the Yelitenda area of the probable labor influx with respect to increased demands for housing, health, other social services, and availability of feed stuffs and other essential commodities in surrounding market towns.

Appendix Eight

PERSONS WHO ASSISTED IN STUDY

United Kingdom

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Peter Henry, Forester, ODA, London
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Elaine Kenworthy, Head Map Librarian, DIS
Sandy Leslie, Agriculturist, LRDC, ODA, Surbiton
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D.M. Robertson, Peat, Marwick, Mitchell & Co., London
Mrs. Townsend, Assistant Gambia Desk Officer, ODA, London
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Howard Wright, CFI, Oxford

The Gambia

Manuel Alers-Montalvo, Mixed Farming Project, USAID, Yundum
Mary Ames, Associate Director, Peace Corps, Banjul
M. Asay, USAID, Banjul
B.A. Baldeh, District Commissioner, Mansa Konko
M.F. Bangura, F/Assistant, I/C W/D, Kombo and Banjul
Abdullai Bittaye, Coordinator for RVTP, Mansa Konko
Fodayg Botang, Forest Officer, Yundum
Eddie Brewer, Conservator of Parks & Wildlife, Abuko
Omar M'Bye, State Counselor, Attorney General's Chambers, Banjul
Ansumana B. Camara, Gambia River Transport Co., Ltd.
Bemba Ceesy, Agriculturalist, Farafenni
J. Ceesay, Soil and Water Management Unit, Ministry of Agriculture, Yundum
Malik Ceesay, Traditional Youth Leader, Farafenni
Ousman Ceesay, Pumping Station, Bund Road
S. Ceesay, Agricultural Research, Capt St. Mary
J.M. Chapman, Deputy Director, PUD, Banjul
John H. Dalton, Agricultural Planning Economist, UNDP
Kebba S. Dampha, Executive Officer, Central Bank, Banjul
Alhagie Bakany Sunua Dibba, Political Party Chairman, Farafenni
Mr. Dibba N'Dow, Manager, Tendaba Resort
Dr. Wally N'Dow, Secretary, Gambia CILSS Program
Halifa Drammeh, Fisheries Department, Banjul
S.A. Drammeh, Operations Officer, The Gambia Produce Marketing Board
J.A. Kino Edu, Anglican Vocational Training Center, Farafenni

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Mohammed Duwa Fofana, Forest Guard, Sankwia Village
Mohammed Duwa Fofana, Agricultural Extension Worker, Balanghar
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Anthony Funicello, USAID
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Cherno Gagyn, Director, Department of Social Welfare, Banjul
Suwaro Gassama, Contractor
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M.A. Gibril, Department of Statistics, The Gambia Customs, Banjul
Wallace Grant, Solicitor, AG's Office, Banjul
Edward E. Hafner, Pumping Station, Bund Road
Shairh Hossain, Chief Accountant, GPMB, Banjul
Boon Jack, Deputy Permanent Secretary, WREN
A. Jacobs, A. Jacobs, Ltd., Banjul
Tamsir Jagne, Principal Agricultural Officer, Jenoi
Mr. Jagne, Permanent Secretary of Agriculture, Banjul
Ms. Jagne, Assistant District Commissioner, LRD, Mansa Konko
Mr. Jallow, GUC, Farafenni
Mr. Jallow, Water Laboratory, Abuko
Mr. Jallow, wood carver, Farafenni
Habibou Jallow, retail fuel dealer, Bakau
Ousman Jallow, head fisherman, Farafenni
K.M. Jallow, Manager, GPMB, Banjul
Chief Kebba T. Jammeh, Farafenni
Alkali Janju, lumber dealer, Banjul
Hassan Jeng, Director, Public Works Department
Mrs. N'dey Oley Jobe, Indigenous Business Advisory Service, Farafenni
C.O. Joof, Fisheries Department, Banjul
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Hannah King, Acting Director, Fisheries Department, Banjul
Chief B. Kinteh, Pakali Nding
Mrs. Mary Langly, Permanent Secretary, Establishment Office, Banjul
Major Clive Lee, Pioneer Unit, Farafenni
Lance Lysack, CUFS, Jenoi
Marc Madland, USAID, Banjul
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Mr. Mambouray, Superintendent, Agriculture Ministry Workshop, Yundum
Buly M'Boge, Forest Guard, Farafenni
Omar Dudu M'Bye, State Counsel, AG's Office, Banjul
Robert J. McEwan, Director, Forestry Department, WREN
Thomas Mosher, USAID, Banjul
Mr. Myaen, Manager, GPMB plant, Kau-Ur

Harvey Nessmith, USAID, Yundum
Mr. N'Jie, Manager, GPMB plant, peanut shells
Edi N'Jie, Director, Water Resources, WREN
Miss Ndeye Isatou N'Jie, Officer in Charge, Abuko Laboratory, Department of Water Resources, Abuko
Omar N'Jie, In-Plant Officer, RVTP, Banjul
Sam N'Jie, E.O., WREN, Banjul
Dodon Nyang, Registrar, Department of Cooperatives, Banjul
A.K. Nye, Ministry of Economic Planning, Banjul
H. Oliver, Former Government Official, Bakau
Ousman Othman, Permanent Secretary, WREN
Mr. Papiwot, carpenter, Sera Kunda
Richard Parker, Gambia Port Authority
Ms. Patricia Pearse, Climate Section, Water Resources, Banjul
Jeffrey Plant, Technical Officer, British High Commission
Dr. D.R.L. Prabakher, Water Resources, WREN
Kevin Proctor, Peace Corps, Banjul
Mr. Ramgobal, Commercial and Development Bank, Banjul
Ivan Ratcliff, Soil and Water Management Unit, Ministry of Agriculture, Yundum
Norman Richards, Peace Corps, Farafenni
Peter Richardson, Jacobs Ltd., Banjul
Khalilou Sali, President, Director General, ORGATEC
Capt. Sallah, Gambia Port Authority, Banjul
Boto Sanneh, Forester, Kau-ur
Paul M. Sarlin, CILSS, Banjul
M'Bye B. Sauaje, GRT, Banjul
Dr. I. Schmiedeberg, Medical Officer, Mansa Konko
Dieter Schultze, Freedom from Hunger Project, Banjul
Sori Sedi, Contractor
Mr. Serika, boat builder, Banjul Harbor
J.K. Sidibeh, Sawmill Superintendent, Nayami Park, Yundum
D. Stewart, Geology Department, Lands Office, Banjul
Sapia Sunphatch, National Training Program, Establishment Office
A.S.O. Taal, Agricultural Planner, Ministry of Agriculture
Boubacarr Taal, Rhun Palm Dealer
Bye Mass Taal, Assistant Director, Forestry Department, WREN
Saihou Taal, Director, Soils Laboratory, Yundum
Solomon Tamoh, Fisheries Department, Gunjur
Gerhard Thaller, Gambia/German Forestry Project, Brikama
Axel Toma, Freedom from Hunger Project, Jenoi
D. Tommy, Department of Water Resources, Banjul
Chief Toure, Darusalam Village
Philip Travis, Peace Corps, IBAS, Farafenni
Royd Van Haght, Power Engineer, GPMB
Richard Waterfield, Peace Corps, Kuntaur, Wassu
Sam Wedderburn, Sociologist, Ministry of Agriculture, Banjul
Celeste Welty, Entomologist, Yundum
Thomas Winn, Cooperative Specialist, USAID
Chris White, Gambia Utilities Corporation, Banjul

Wood retailers, Bakau, Kau-Ur
Housewives, Bakau
Restaurant operators, Bakau
Blacksmiths, Bakau
Mangrove cutters, Banjul Harbor
Woodcutters, Hudeda
Woodcutter and retailer, Farafenni
Fishermen and fish sellers, Farafenni Market
Firewood dealer, Kau-Ur
Village chiefs and other local people at Soma, Darusalam, Pakali Ba, Mansa Kouko Sererer communities: Banjul, Jarreng, Balingo, Farafenni, and Jenoi.